Naval Postgraduate School
Monterey, California 93943-5138

NPS-09-02-020

SUMMARY OF RESEARCH 2001

Department of Aeronautics and Astronautics
Graduate School of Engineering and Applied Sciences

Max F. Platzer
Chair

Raymond P. Shreeve
Associate Chair for Research

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Prepared for: Naval Postgraduate School
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Monterey, California

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13. ABSTRACT (Maximum 200 words.)

This report contains project summaries of the research projects in the Department of Aeronautics and Astronautics. A list of recent publications is also included, which consists of conference presentations and publications, books, contributions to books, published journal papers, and technical reports. Thesis abstracts of students advised by faculty in the Department are also included.

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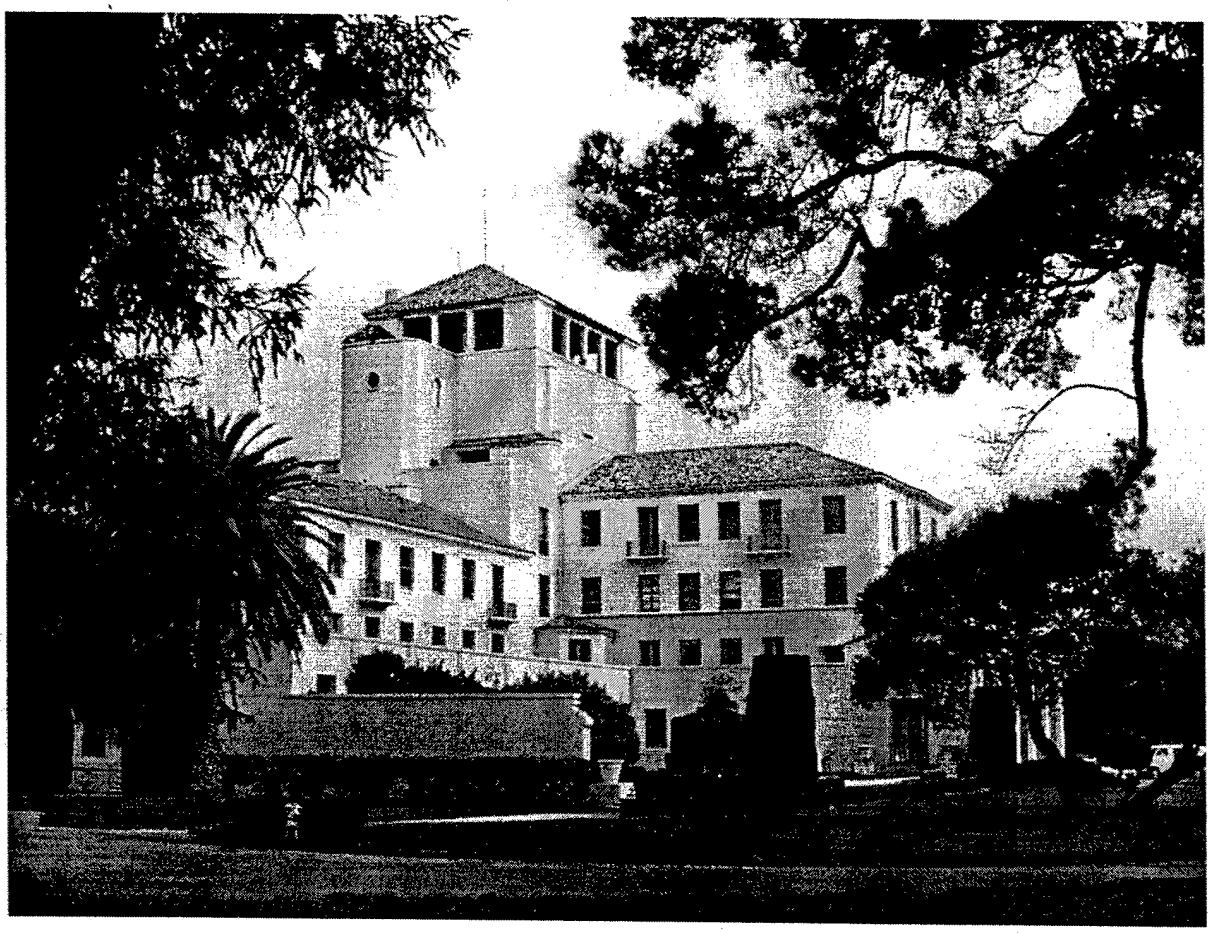

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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the four graduate schools (School of International Graduate Studies, Graduate School of Operations and Information Sciences, Graduate School of Engineering and Applied Sciences, and Graduate School of Business and Public Policy) and three Research Institutes (The Modeling, Virtual Environments, and Simulation (MOVES) Institute, Institute for Information Superiority and Innovation (I2SI), and Institute for Defense System Engineering and Analysis (IDSEA). This volume contains research summaries for the projects undertaken by faculty in the Department of Aeronautics and Astronautics during 2001. The summary also contains thesis abstracts for those students advised by Aeronautics and Astronautics faculty during 2001.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the Naval Postgraduate School Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil/~code09/

Additional published information on the Naval Postgraduate School Research Program can be found in:

- *Compilation of Theses Abstracts:* A quarterly publication containing the abstracts of all unclassified theses by Naval Postgraduate School students.
- *Naval Postgraduate School Research*: A tri-annual (February, June, October) newsletter highlighting Naval Postgraduate School faculty and student research.
- *Summary of Research*: An annual publication containing research summaries for projects undertaken by the faculty of the Naval Postgraduate School.

This publication and those mentioned above can be found on-line at:
http://web.nps.navy.mil/~code09/publications.html.

INTRODUCTION

The research program at the Naval Postgraduate School exists to support the graduate education of our students. It does so by providing military relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, and maintains the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focused graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at the Naval Postgraduate School consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with government laboratories and universities, provides off-campus courses either on-site at the recipient command, by VTC, or web-based, and provides short courses for technology updates.

- Naval Postgraduate School Institutionally Funded Research (NIFR) Program: The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursably sponsored, and (4) to cost-share the support of a strong post-doctoral program.

In 2001, the level of research effort overall at the Naval Postgraduate School was 148 faculty work years and exceeded $48 million. The reimbursable program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY2001, over 93% of the research program was externally supported. A profile of the sponsorship of the Naval Postgraduate School Research Program in FY2001 is provided in Figure 1.

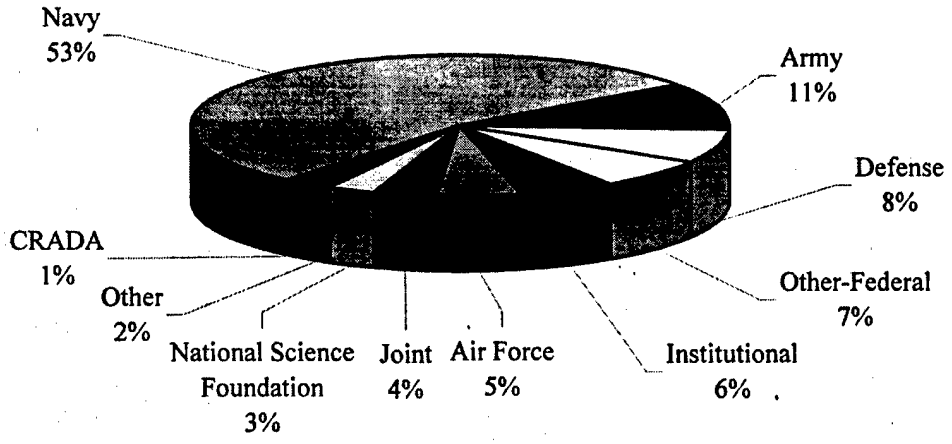


Figure 1. Profile of NPS Research and Sponsored Programs ($52M)

The Office of Naval Research is the largest Navy external sponsor. The Naval Postgraduate School also supports the Systems Commands, Warfare Centers, Navy Labs and other Navy agencies. A profile of external Navy sponsorship for FY2001 is provided in Figure 2.

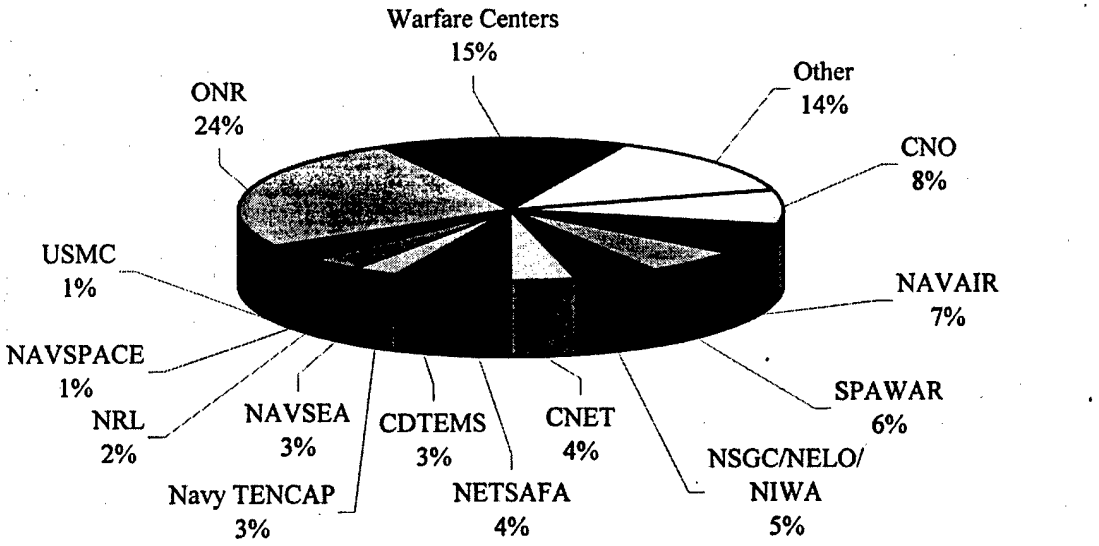


Figure 2. Navy External Sponsors of NPS Research and Sponsored Programs ($29M)

These are both challenging and exciting times at the Naval Postgraduate School and the research program exists to help ensure that we remain unique in our ability to provide education for the warfighter.

DAVID W. NETZER
Associate Provost and Dean of Research

September 2002

DEPARTMENT OF ASTRONAUTICS AND AERONAUTICS

MAX PLATZER
CHAIR

DEPARTMENT SUMMARY

OVERVIEW:

The Department of Aeronautics and Astronautics is an integral part of the Graduate School of Engineering and Applied Sciences. Aero/Astro faculty members conduct research and teach courses covering air and space vehicles, missiles, propulsion, aerodynamics, avionics, control systems, structures, turbomachinery, computational and experimental methods, orbital mechanics and combat survivability that emphasize total systems design. The uniqueness of this approach is that air and space vehicles are considered part of a larger combat system that includes all aspects of warfighting.

Navy and Marine Corps aircraft are designed to operate abroad ships as part of a larger battlegroup. Challenges normally not considered by aircraft operating from land bases become design constraints for shipboard compatibility. By working in a Total System Design Group, Aero/Astro faculty and students are exposed to the constraints of shipbuilding, software development and weapons compatibility. Additional issues such as acquisition methods, analysis of alternatives, and order of battle scenarios can be explored by working with the Graduate School of Business and Public Policy, the Graduate School of Operations and Information Sciences, and the School of International Graduate Studies. Aero/Astro faculty and students are exposed to a wide variety of disciplines to develop capable runway-independent aircraft and robust space systems.

CURRICULA SERVED:

- Aeronautical Engineering (Curriculum 610)
- Engineering/Avionics (Curriculum 611)
- NPS-TPS Cooperative Program (Curriculum 612)
- Space Systems Engineering (Curriculum 591)

DEGREES GRANTED:

- Master of Science in Aeronautical Engineering
- Master of Science in Engineering Science
- Master of Science in Astronautical Engineering
- Aeronautical and Astronautical Engineer
- Doctor of Engineering

RESEARCH THRUSTS:

- Aerospace Vehicle Design
- Aerodynamics, Aeroelasticity, V/STOL Aircraft Technology
- Flight Mechanics and Controls
- Structures, Structural Dynamics, Composite Mechanics, Fracture and Fatigue
- Propulsion and Gas Dynamics
- Avionics
- Rotary Wing Aircraft Technology
- Aircraft Combat Survivability
- Spacecraft Systems, Attitude Control and Smart Structures
- Spacecraft Guidance, Control and Optimization

RESEARCH FACILITIES:

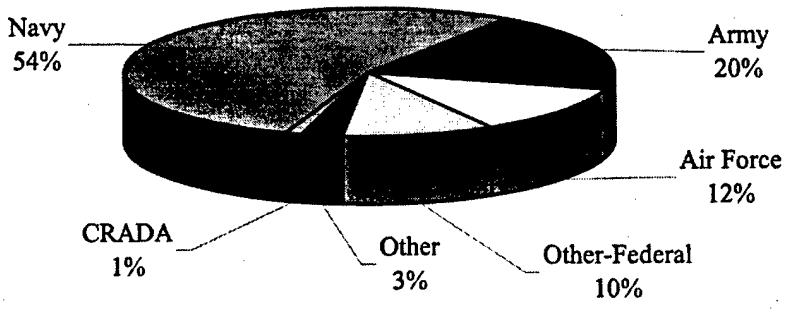
- Aeronautical Engineering Laboratories:
  - Aerodynamics Laboratory
  - Gas Dynamics Laboratory
  - Combustion Laboratory
  - Turbo-Propulsion Laboratory
  - Computation Laboratory
  - Flight Mechanics Laboratory
  - Structures and Composite Laboratory
  - Controls Laboratory
  - Avionics Laboratory
  - Survivability and Lethality Assessment Laboratory
  - Rotorcraft Laboratory
  - Aeronautics Design Laboratory
- Spacecraft Laboratories:
  - FLTSATCOM Laboratory
  - Spacecraft Test Laboratory
  - Spacecraft Attitude Dynamics Laboratory
  - Spacecraft Design Laboratory

RESEARCH CENTERS:

- Navy-NASA Joint Institute of Aeronautics
- Spacecraft Research and Design Center
- Turbo-Propulsion Laboratory
- Vertical Flight Technology Center
- Aerodynamics Decelerator Systems Center

RESEARCH PROGRAM (Research and Academic)-FY2001:

The Naval Postgraduate School's sponsored program exceeded $49 million in FY2001. Sponsored programs included both research and educational activities funded from an external source. A profile of the sponsored program for the Department of Aeronautics and Astronautics is provided below:



Size of Program: $2861K

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SPACECRAFT SYSTEMS

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Space and Naval Warfare Systems Command

OBJECTIVE: The goal of this project is to develop and operate spacecraft laboratories to provide noteworthy improvements to Space Systems Engineering Curriculum. The laboratories are: FLTSATCOM Laboratory, Spacecraft Attitude Dynamics and Control Laboratory, Smart Structures Laboratory, and Spacecraft Design Center.

SUMMARY: During 2001, several major achievements have been made in the development of these laboratories and their usage for the courses and thesis work by the students. The students in a course have used FLTSATCOM Laboratory by sending commands to the satellite for momentum wheel spin-up and firing of thrusters, and analyzing the telemetry data. Students in spacecraft attitude control course have used three-axis-attitude control simulator. Aerospace Conceptual Design Center (CDC) software has been implemented at the Spacecraft Design Center. Under spacecraft design course, the students designed an EHF (Extremely High Frequency) communications satellite. Applications of micro-electromechanical system (MEMS) for the components of nanosatellites such as thrusters, sensors and rate gyros were evaluated. Nanosatellite formation designs were also analyzed.

PUBLICATIONS:

Agrawal, B. and Okano, S., "Microelectromechanical Systems for Space Applications," *Proceedings of the 11th International Workshop on Physics of Semiconductor Devices*, New Delhi, India, 11-15 December 2001.

THESES DIRECTED:

Palermo, W., "Angular Rate Estimation for Multi-Body Spacecraft Attitude Control," Masters Thesis, Naval Postgraduate School, June 2001.

Abreu, M., "Conceptual Design Tools for the NPS Spacecraft Design Center," Masters Thesis, Naval Postgraduate School, June 2001.

Tomlin, S., "Remote Nanosatellite Formation Design with Orbit Perturbation Corrections and Attitude Control/Propulsion Subsystem Correlation," Masters Thesis, Naval Postgraduate School, June 2001.

Okano, E., "Microelectromechanical Systems for Small Satellite Applications," Masters Thesis, Naval Postgraduate School, June 2001.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Spacecraft Design, Spacecraft Attitude Control, Space Manipulator

BIFOCAL RELAY MIRROR TECHNOLOGY DEVELOPMENT

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: National Reconnaissance Office

OBJECTIVE: This is NRO Director's Innovative Initiative project. The objective is to evaluate different paths in the development of fine acquisition, tracking and pointing (ATP) and beam control optics technologies for the Bifocal Relay Mirror spacecraft, do preliminary development work, and design a test bed for the development of these technologies.

SUMMARY: A team from NPS, AFRL, and Boeing performed the work on the project. Under this effort, nine tasks were performed: state-of-art technologies in ATP and beam control of optics; analytical model of the spacecraft with two gimbaled telescopes; novel electro-optical systems for beam control that are more suited for space-borne platform; target tracking systems for both cooperative and uncooperative targets; options for integrated optics and spacecraft control system design; simulations of control options; experiments to validate the acquisition, tracking and pointing control of a laser beam using steering mirrors integrated into NPS Three-Axis-Spacecraft Simulator; design of test bed to demonstrate end-to-end bifocal relay mirror spacecraft beam control, acquisition, tracking, and pointing performance; and future development efforts. The project has provided a road map for the development of this challenging technology.

PUBLICATIONS:

Agrawal, B. and Senenko, C., "Attitude Dynamics and Control of Bifocal Relay Mirror Spacecraft," AAS 01-418, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

THESES DIRECTED:

Chernesky, V., "Development and Control of a Three-Axis-Satellite Simulator for the Bifocal Relay Mirror Spacecraft," Masters Thesis, Naval Postgraduate School, December 2001.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Relay Mirror Spacecraft, Acquisition, Tracking, Pointing

METHOD OF SLEWING THE SPACECRAFT TO MINIMIZE SETTLING TIME

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Secretary of the Air Force

OBJECTIVE: The spacecraft have low frequency solar array flexible modes, which are excited during the slew maneuver. These flexible modes limit the control bandwidth and degrade the pointing error at the end of slew maneuver. The objective of this project is to develop methods to shape the torque profiles of CMGs for the slew maneuver such that at the end of slew, the vibrations are eliminated or minimized and the attitude errors are within the limits.

SUMMARY: The analytical model of NPS Flexible Spacecraft Simulator was used to evaluate different torque profiles. The torque profiles analyzed were Bang-Bang, Versine, Smoothed Bang-Bang, and Input Shaped. Using feed-forward of the torque profile reduces significantly the vibrations at the end of the slew maneuver, but it requires the inertia to be identified very accurately. A small value of the smoothing parameter is effective enough to greatly improve the performance of the Bang-Bang profile. For tight tolerance on attitude control, input shaping is most effective in meeting settling time performance.

PUBLICATIONS:

Song, G. and Agrawal, B., "Vibration Suppression of Flexible Spacecraft During Attitude Control," *Acta Astronautic,* Vol. 49, No. 2, pp. 73-83, 2001.

DoD KEY TECHNOLOGY AREASS: Space Vehicles, Sensors, Computing and Software

KEYWORD: Spacecraft Slewing

SWARM-FORMATION SATELLITE SYSTEM DESIGN

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: National Reconnaissance Office

OBJECTIVE: The objective of this project is to participate with the University Team, MIT, Stanford, and CALTECH on the design of Swam-Formation Satellite System. The emphasis by the NPS team will be on the mission and payload definition. The application of spacecraft design tools at the NPS spacecraft design center for use by distributed collaborative design team will be also evaluated.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Spacecraft Design, Automated Design, Distributed Design

VIBRATION SUPPRESSION AND ISOLATION IN THE IMAGING SPACECRAFT

Brij N. Agrawal, Professor
Department of Aeronautics and Astronautics
Sponsor: Secretary of the Air Force

OBJECTIVE: For an imaging satellite, vibration isolation of the imaging sensor is a critical requirement to meet its performance. For future imaging satellites with higher performance requirements, vibration isolation becomes even more critical. The objective of this project is to assess vibration suppression and isolation technologies.

SUMMARY: Under this effort, both passive and active damping techniques and different vibration isolation control techniques were evaluated. The passive damping techniques considered were viscoelastic materials, viscous fluids, eddy current damper, smart materials, and impact damper. For active control, both piezoelectric and voice coil actuators were considered. Vibration isolation techniques on previous imaging satellites and satellite under development were analyzed. In general, active damping is used for lower frequencies and passive damping for higher frequencies. Most spacecraft require a hybrid system, passive and active, to suppress the entire range of disturbance frequencies.

PUBLICATIONS:

Song, G., Schmidt, S. and Agrawal, B., "Experimental Robustness Study of Positive Position Feedback Control for Active Vibration Suppression," *Journal of Guidance, Control, and Dynamics*, Vol. 25, No. 1, January-February 2002.

PRESENTATIONS:

Chen, H., Agrawal, B. and Longman, R., "Approaches to Matched Basis Function Repetitive Control," AAS-01-369, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Chen, H., Agrawal, B., Longman, R., Phan, M. and Edwards, S., "Rejection of Multiple Unrelated Periodic Disturbances Using MELMS with Disturbance Identification," AAS/AIAA Space Flight Mechanics Meeting, Santa Barbara, CA, 11-15 February 2001.

THESES DIRECTED:

Tarranti, C., "A Computationally Efficient Algorithm for Disturbance Cancellation to Meet the Requirements for Optical Payloads in Satellites," Ph.D. Dissertation, Naval Postgraduate School, September 2001.

Barney, T., "Adaptive Multi-Layer Controller Design and Its Application to Active Vibration Suppression on a Space Truss," Masters Thesis, Naval Postgraduate School, June 2001.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Sensors, Computing and Software

KEYWORDS: Vibration Suppression

EFFECTS OF ROCKET MOTOR FILM-COOLED OPERATION ON EXHAUST PLUME SOOT PROPERTIES

Christopher M. Brophy, Research Assistant Professor
David W. Netzer, Distinguished Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Air Force Phillips Laboratory

OBJECTIVE: To obtain the optical properties, physical size, and mass loading of soot present in a liquid fueled Kerosene/Oxygen rocket engine and to evaluate the effects of using a film-cooled combustor's wall.

SUMMARY: The soot mass loading and associated optical properties in the exhaust of a film-cooled liquid rocket engine burning gaseous oxygen with hydrocarbon fuels were measured. The exhaust plume without film cooling was characterized over an oxygen-to-fuel (O/F) range of 0.4 to 1.5 to find soot properties expected in the fuel-rich film region. The derived baseline soot production curves for JP-8 and JP-8+100 were similar to kerosene. Soot levels derived for JP-10 were much higher than JP-8 and the predicted values over the same O/F range. Operating the engine with a core O/F of 1.5, film cooling mass-flow percentages were varied over a range of 6 to 21% of total reactants. Film layer thickness and soot mass loading both increased as percent film cooling increased. The rocket engine was operated with and without film cooling during the same run to obtain properties for the plume core and plume core with film cooling under nearly identical engine operating conditions. A vortex ring segment was used to tangentially inject the film layer. A multi-wavelength, fiber optic transmission technique, using the transmission ratio of five wavelengths (from the visible to the near IR) through the exhaust plume, was used to determine the amount of soot present.

PUBLICATIONS:

Searles, D.S., Brophy, C.M., Sinibaldi, J.O., Venner, M.J. and Johnson, C.W., "Soot Production Characteristics for JP-8, JP-8+100 and JP-10," 27th JANNAF EPTS, Brooks Air Force Base, San Antonio, TX, November 2001.

THESIS DIRECTED:

Searles, D.S., "Optical Characterization of Soot Properties in a Film-Cooled Kerosene/Oxygen Exhaust Plume," Masters Thesis, Naval Postgraduate School, December 2001.

DoD TECHNOLOGY AREA: Other (Missile Signatures)

KEYWORDS: Missile, Propulsion, Signature, IR, Soot

DEVELOPMENT OF A FIBER OPTIC TOMOGRAPHIC IMAGING DIAGNOSTIC TO MAP COMBUSTION SPECIES WITHIN ROCKET EXHAUST PLUMES

Christopher M. Brophy, Research Assistant Professor
David W. Netzer, Distinguished Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsors: Ballistic Missile Defense Organization and U.S. Air Force Research Laboratory

OBJECTIVE: To develop an optical diagnostic that can map in three-dimensions the combustion species' concentrations within a rocket exhaust plume. Furthermore, remote location of expensive infrared spectrometers is desired in order to protect them from the harsh environment created during rocket motor operation.

SUMMARY: Interest in accurate detection and targeting of aggressor missiles has received considerable interest with the national priority of developing a missile defense system. Understanding the thermal signatures of the exhaust plumes of such missiles is key to accomplishing that mission. Before signature models can be precisely developed for specific rockets, the radiation of the molecular or combustion species within those plumes must be accurately predicted. A combination translation / rotation scanning diagnostic technique has been developed to map the combustion species of a rocket plume and characterize its radiation properties. Using new infrared spectrometer and fiber optic cable technology to transmit the signal spectrum of interest, the custom designed mechanism can sweep through two dimensions of a steady-state rocket exhaust. A glow bar, or blackbody simulator, is shuttered on the opposite side of the plume, allowing the spectrometer to measure both the emission and absorption spectra. This thesis demonstrated the first time use of fiber optic cable to transmit infrared emission / absorption (E/A) spectra from a rocket plume to an infrared detector. This new fiber optic configuration allows for rapid translation and rotation around the rocket plume, establishing the capability for rapid spatial characterization of the combustion species present. Experimental results may then be compared to DoD rocket plume model predictions to highlight areas for improvement.

THESIS DIRECTED:

Kutrieb, J.M., "Rocket Plume Tomography of Combustion Species," Masters Thesis, Naval Postgraduate School, December 2001.

DoD TECHNOLOGY AREA: Other (Missile Signatures)

KEYWORDS: Rocket Plume Exhaust, Spectral Imaging, Emission/Absorption, Combustion Species, Signature

DEVELOPMENT AND CHARACTERIZATION OF A LIQUID HYDROCARBON FUELED PULSE DETONATION ROCKET ENGINE

Christopher M. Brophy, Research Assistant Professor
David W. Netzer, Distinguished Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: To develop and measure the performance of a liquid hydrocarbon fueled pulse detonation engine (PDRE) at varying operating conditions. The secondary objective was to characterize the propulsive efficiency of the PDRE using different fuels at partial fill conditions.

SUMMARY: A liquid hydrocarbon-fueled PDRE was built and successfully tested at the Naval Postgraduate School's Rocket Propulsion and Combustion Laboratory. The first time use of a new electro-hydraulic liquid fuel injector was demonstrated to produce consistent atomization properties while allowing for varying fuel injection durations at frequencies up to 50Hz. Planar laser-induced fluorescence and high-

speed imaging were used to characterize the injection flow paths of this injector. Using gaseous ethylene as a baseline for comparison, the PDRE was operated at various equivalence ratios and frequencies up to 40 Hz. Operation in partial fill scenarios was successfully conducted and found to deliver a decreased impulse linearly related to the percentage fill. A series of tests was conducted using liquid JP-10 and RP-1 fuels over varying oxidizer-to-fuel ratios. The higher pressures, wave speeds, and resulting impulse measurements revealed the benefits of using high energy density hydrocarbon fuels. The difficulty in detonating these fuels was demonstrated and overcome using a variety of different geometries and hardware configurations.

PUBLICATIONS:

Brophy, C.M., Damphousse, P.E. and Sinibaldi, J.O., "Initiator Performance for Liquid-Fueled Pulse Detonation Engines," AIAA2002-0472, 40th AIAA Aerospace Sciences Meeting, Reno, NV, January 2002.

THESIS DIRECTED:

Damphousse, P.E., "Characterization and Performance of a Liquid Hydrocarbon-Fueled Pulse Detonation Rocket Engine," Masters Thesis, Naval Postgraduate School, December 2001.

DoD TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Detonation, Pulse Detonation Rocket Engine, Hydrocarbon Fuels, Space Propulsion

TECHNOLOGY INVESTIGATION FOR PULSE DETONATION ENGINES

Christopher M. Brophy, Research Assistant Professor
David W. Netzer, Distinguished Professor
Jose O. Sinibaldi, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: General Electric Aircraft Engines

OBJECTIVE: To investigate Pulse Detonation Engine's (PDE) auxiliary systems by determining minimum and optimum parameters for successful PDE operation. The secondary objective was to fully characterize those systems and their effects on overall PDE performance.

SUMMARY: Air-blast BETE atomizers were used to determine the maximum Sautter Mean Diameter (SMD) for JP8 – air spray mixtures through which a detonation wave can propagate successfully. Successful PDE operation was observed at 7Hz for JP8 sprays with SMD values less than 3.0 μm and 70% of the fuel mass in gaseous state. Larger SMD values and less than 70% fuel in gaseous state yielded unsuccessful detonation propagation. Detonation initiation was carried out via a pre-detonator where the BETE atomizers were used with JP8-Oxygen and ignition energy studies indicate that a minimum of 30mJ are needed to initiate a JP8 – Oxygen spray with SMD values between 10 and 13 μm and 0% of the fuel in the gaseous state. But more interestingly, for reliable detonation initiation, a minimum of 100mJ ignition energy levels is required. Shock focusing studies directed towards shock-induced detonation initiation were carried out with minimum improved performance, furthermore focusing of shock waves with an initial (and impractical) Mach number greater than 2.5 would be required to reliably initiate a detonation wave. In order to pursue the development of a JP8 – Air detonation initiator, a new fuel injector is required capable of producing JP8 sprays with SMD values less than 6 μm, in a cyclic operating mode at a rate of up to 100 Hz. After an extensive industry research and review, these injector requirements pointed toward a custom design made possible by Sturmann Industries. Four injectors and their respective electronic control modules were ordered and preliminary characterization has started. Promising results indicate JP8 sprays with SMD values between 7 and 10 μm can be generated at up to 100Hz operation.

PUBLICATIONS:

Brophy, C.M., Sinibaldi, J.O. and Netzer, D.W., "Effects on Fuel Distribution on Pulse Detonation Engine Operation and Performance," 15th International Symposium on Air Breathing Engines, Bangalore, India, September 2001.

Brophy, C.M., Sinibaldi, J.O. and Sexton, N., "Fuel/Air Initiator Development for Pulse Detonation Engines," *Proceedings of the 18th International Colloquium on the Dynamic of Explosions and Reactive Systems*, Seattle, WA, 29 July–3 August 2001.

THESIS DIRECTED:

Sexton, N.G., "Detonability of Hydrocarbon/Air Mixtures Using Combustion Enhancing Geometries for Pulse Detonation Engines," Masters Thesis, Naval Postgraduate School, June 2001.

DoD TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Detonation, Pulse Detonation Engine, Fuel Injectors, Ignition Systems

FUNDAMENTAL STUDIES OF LIQUID-FUELED PULSED DETONATION ENGINES

Jose O. Sinibaldi, Research Assistant Professor
David W. Netzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: To understand fundamental properties of initiation and propagation of liquid-fueled detonations in order to develop future pulse detonation engine systems.

SUMMARY: Design and construction of a valveless Pulsed Detonation Engine (PDE) was completed and successful operation of up to 10 Hz were attained using liquid-fuels, and up to 40Hz with gaseous hydrocarbon fuels. Ignition energy effects on deflagration to detonation transitions (DDT) showed a minimum spark with 20mJ of energy is required to initiate a propane-air or ethylene-air DDT process, but optimum DDT was obtained with a 100mJ spark. Detonation diffraction studies required to set up the following simultaneous optical diagnostics: a) high-speed digital Schlieren/Shadowgraph system capable of 17 images at a rate of up to 150 kHz with a maximum resolution of 512x512 pixels; b) a high-speed CH* chemiluminescence imaging system with similar performance to the Schlieren system. These diagnostics were applied to detonation waves diffraction from a 2" diameter tube into a 5" diameter tube, respectably the pre-detonator and the main combustor tube of a valveless PDE. Diffraction studies indicate that a minimum of 7 detonation wave cell widths are needed in the pre-detonator in order for the detonation wave to successfully diffract into the PDE main combustor. These results are an indication of the detonable mixtures' kinetic rates and further investigations are deemed necessary to obtain quantitative results.

PUBLICATIONS:

Brophy, C.M., Sinibaldi, J.O. and Netzer, D.W., "Effects on Fuel Distribution on Pulse Detonation Engine Operation and Performance," 15th International Symposium on Air Breathing Engines, Bangalore, India, September 2001.

Brophy, C.M., Sinibaldi, J.O. and Sexton, N., "Fuel/Air Initiator Development for Pulse Detonation Engines," *Proceedings of the 18th International Colloquium on the Dynamic of Explosions and Reactive Systems*, Seattle, WA, 29 July–3 August 2001.

DoD TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Detonation, Pulse Detonation Engine, Fuel Injectors, Ignition Systems

CONTROL COMPRESSIBLE DYNAMIC STALL USING A VARIABLE DROOP LEADING EDGE VR-12 AIRFOIL

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army (NASA) Aero Flight Dynamics Directorate

OBJECTIVE: To investigate compressible dynamic stall control using a Variable Droop Leading Edge (VDLE) Concept.

SUMMARY: In an attempt to meet the US Army TDA, a new way of controlling dynamic stall that can exploit the progress in smart materials, the concept of drooping an airfoil leading edge steadily as it pitches up to high angles of attack is being tested in this project. The technique holds special promise for compressible dynamic stall control since it is a leading edge type of stall. A 6-inch chord VR-12 (Boeing Vertol) airfoil has been designed, and fabricated with 20 unsteady pressure transducers installed on it. The design incorporates features to bring out all the power and signal leads through the ¼-chord point, the only stationary point in the system. The leading 25% of the airfoil can droop to as large as –25 degree relative to the main element dynamically and it can be preset to any desired value as well. A comprehensive data acquisition and processing software has been developed for online, real time display of the large sample set of unsteady data that is collected during the tunnel runs. Both instantaneous and ensemble averaged data along with integrated quantities can be displayed in real time. The pressure transducers were individually calibrated using suction cups to enhance measurement accuracy. Testing is now ongoing. Already, preliminary data has been collected for various flow conditions and integrated force and moment loops calculated. This early data set has shown that the concept and the studies are worth further exploration and hence, detailed testing is planned for CY 2002. The project is now also a specific task in the U.S. Army (AFDD) - German DLR MOU program.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Variable Geometry Airfoils, Dynamic Stall, Rotor Blade Flow Control

EXPERIMENTAL STUDIES OF COMPRESSIBLE DYNAMIC STALL

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army (NASA) Aero Flight Dynamics Directorate

OBJECTIVE: To investigate compressible dynamic stall control using the oscillatory blowing technique on a trailing edge stalling oscillating NACA 0015 airfoil.

SUMMARY: This effort aims to control compressible dynamic stall using oscillatory blowing from a Boeing Company supplied actuator through a 0.02-inch slot in a 6-inch chord NACA 0015 airfoil. This work is also being carried out as a specific task in the U.S. Army (AFDD)/ Israel MOU. Preliminary trials at controlling stall were found to be partly successful. Considerable difficulties were experienced by the strong airfoil peak suction pressure, which caused the actuator diaphragm to be held at one end of its stroke, largely eliminating its pumping functionality. Enclosing the actuator in a controlled vacuum chamber was expected to mitigate these problems as was confirmed by further tests. But, the primary limitation was the fact that as the flow Mach number was increased, the blowing capabilities required increased significantly and a need for multiple actuators became apparent. Also, the frequency requirements became high for the actuators available. A new manifold system has been designed which can house two separate blowers, with the air path through the outlet ducting optimized for enhanced performance to be derived from a synchronous operation of the actuators. Further work in this regard is contingent upon AFDD providing the support to fabricate this design.

PUBLICATIONS:

Chandarsekhara, M.S., "An Exploratory Investigation of Pulsatile Blowing to Control Compressible Dynamic Stall over an Oscillating NACA 00125 Airfoil," Final Report submitted to the U.S. Army Research Office, April 2001 with copy to AFDD.

PRESENTATIONS:

Tung, C., Dr., "Experimental Studies of Compressible Dynamic Stall," US Army /Israel MOU meeting, Israel, March 2001.

Chandrasekhara, M.S. and Tung, C., Dr., "Experimental Studies of Compressible Dynamic Stall," AFDD at NASA ARC, October 2001.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Flow Control, Helicopter Blade Stall, Oscillatory Blowing

FLUID MECHANICS OF COMPRESSIBLE DYNAMIC STALL CONTROL USING DYNAMICALLY DEFORMING AIRFOILS

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: To develop flow control schemes through management of the unsteady vorticity field by dynamically deforming an airfoil for prevention of flow separation.

SUMMARY: This year the project was focused on further testing of the 6-inch chord NACA 0012 airfoil instrumented with 148 surface hot-film gages to identify the surface shear stress behavior in this flow at conditions representative of a helicopter retreating blade. Detailed analysis of the data was carried out using MATLAB tools and also, some other tools developed in-house. The most spectacular result was the identification of the common precursor to compressible dynamic stall as the rapid rise in surface shear stress for all different dynamic stall onset mechanisms discovered in our earlier investigations. This provides us a new tool with which to attempt to closed-loop control of compressible dynamic stall. Other results with significant implications were the documentation of the shock imprint in the surface flow signature, the dramatic movement of the transition onset point on the airfoil upstroke and the flow relaminarization during its down stroke as it reattaches from the deep stall state, both of which affect all computational studies conducted so far. It is now clear that success in computational fluid dynamic modeling of the flow requires incorporation of the new physics uncovered from these studies. The project has now concluded and a final report to ARO has been submitted.

PUBLICATIONS:

Chandarsekhara, M.S., "Fluid Mechanics of Compressible Dynamic Stall Control Using Dynamically Deforming Airfoils," Final Report submitted to the U.S. Army Research Office, November 2001.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Flow Control, Helicopter Blade Stall, Smart Materials, Deforming Airfoils

SUPPORT OF FSU/FAMU EXPERIMENTAL STUDIES OF COMPRESSIBLE DYNAMIC STALL

M.S. Chandrasekhara, Research Professor
Department of Aeronautics and Astronautics
Sponsor: Florida A&M University

OBJECTIVE: To investigate compressible dynamic stall control using supersonic micro-jets.

SUMMARY: A novel flow control approach that uses blowing a large number of supersonic micro-jets into the flow has demonstrated promise in controlling jet noise and other practical flow issues. Florida State university researchers are now attempting to use the same technique to control compressible dynamic stall. This proof of concept study needs a facility specifically designed for the problem and the NASA/FML Compressible Dynamic Stall Facility is being used for the effort. Assistance to meet the exacting requirements of model design, supporting methods, factors of safety needed to be satisfied at NASA prior to receiving approval for testing a new model and the necessary training to use the facility, the measurement technique of point diffraction interferometry and the custom built electronic phase interlocking system is being provided for the project. At the time of writing, the model design, fabrication with about 540 micro-jets drilled on the airfoil upper surface from the leading edge to x/c = 0.25 is complete. Component integration with the air blowing system is ongoing. It is proposed to use the steady supply of shop air for this effort to blow at about 100 psia pressure to explore the flow control capabilities of this approach.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Micro-jet Blowing, Dynamic Stall, Rotor Blade Flow Control

AIR-GROUND RAPID RETARGETING SYSTEM

Russell W. Duren, Associate Professor
Issac Kaminer, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: The objective of this proposal is to continue to investigate design requirements and technical problems related to the development of a closed system which will accept, transmit and verify weapon targeting information using existing/planned C4I system to provide off-board targeting information to combat aircraft enroute to combat areas.

SUMMARY: Research concentrated on investigating design requirements and technical problems related to the development of a closed system which will generate and transmit targeting information using the existing/planned C4I system to provide off-board retargeting information to a generic GPS-guided standoff weapon. A conceptual system was developed that used generic sensor platforms and a ground-based targeting processor to provide targeting data to a generic standoff weapon via a Link-16 data link. A simulation model was developed in order to investigate the response of the proposed system to various combinations of identified error sources. The preliminary design of a simulation model was completed. Initial coding of the simulation model was performed using Statemate MAGNUM from I-Logix, Inc. Final coding was completed using MATLAB Simulink. The simulation model was developed in a modular fashion to allow future expansion. Initially generic modules are being used for the target behavior, the sensors, the targeting processor, the data link, the weapon flight characteristics, and the weapon effects on the target. Due to the modular nature of the simulation model each of these modules will be capable of being replaced by more sophisticated or less generic modules in the future. Results of simulation with the generic models were used to predict the overall contributories of system variables to weapon accuracy.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Air Vehicles, Path Real-Time Information in the Cockpit, Targeting, Time Critical Strike

ANALYSIS OF TRACKING CHARACTERISTICS AND IDENTIFICATION CONTRIBUTIONS OF DIVERSE SYSTEMS AND DATA SOURCES FOR MULTIPLE SOURCE INTEGRATION/DATA FUSION

Russell W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center - Aircraft Division

OBJECTIVE: The objective of this proposal is to provide a single fused track for each contact of interest in the battlespace using the multiple source integration/data fusion (MSI/DF) concept. This research supports MSI/DF initiatives being developed by PMAS-231, Northrup-Gruman Corporation, and the Office of Naval Research for the E-2C Hawkeye aircraft. A fused track will be representative of all available sources of data contributing to that track. The combat identification (CID) process will tie together all identifying attributes of these tracks to enable a CID decision based on the track identification parameters.

SUMMARY: In the Command and Control mission, new technologies such as 'sensor fusion' are designed to help reduce operator workload and increase situational awareness. This research explored the tracking characteristics of diverse sensors and sources of data and their contributions to a fused tactical picture. The fundamental building blocks of any sensor fusion algorithm are the tracking algorithms associated with each of the sensors on the sensor platform. In support of this study, the MATLAB program 'fusim' was written to provide acquisition managers a tool for evaluating tracking and sensor fusion algorithms. The fusim program gives the user flexibility in selecting: sensor platforms, up to four sensors associated with that platform, the target types, the problem orientation, and the tracking algorithms to be used with the sensors. The fusim program was used to compare tracking algorithms in a multiple sensor/multiple target environment. Specifically, the Probabilistic Data Association Filter, the Interacting Multiple Models Filter, the Kalman Filter and the Constant Gain Kalman Filter were evaluated against multiple maneuvering, non-maneuvering, and fixed targets. It is recommended that this study be continued to evaluate advanced tracking and data association techniques, to expand the program to allow attribute tracking and identification, and to study the Human-Machine Interface aspects of sensor fusion.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Sensor Fusion, Data Fusion, Multiple Source Integration

UHF ELECTRICALLY SCANNED ARRAY (UESA) STUDY

Russell W. Duren, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command

OBJECTIVE: The objective of this proposal is to investigate computer architecture and processing issuer related to the development and testing of a UHF electrically scanned array (UESA).

SUMMARY: Two papers were written related to the UESA system. On paper summarizes computer architectures and benchmarks for the Space-Time Adaptive Processing algorithms required for processing the UESA data. The second paper compares the tactical performance of the proposed UESA antenna to the ADS-18 linear electronically scanned array antenna currently being considered as part of the E-2C Radar Modernization Program.

DoD KEY TECHNOLOGY AREAS: Command, Control and Communication

KEYWORDS: Airborne Early Warning, Avionics, Computer Architecture, Cooperative Engagement Capability, Electrically Scanned Array

CASCADE VORTEX-SHEDDING STUDY

G. V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration - Glenn Research Center

OBJECTIVE: Vortex shedding from the trailing edge of an upstream blade row will increase the frequency of excitation on a subsequent blade row in a multistage compressor. This increased frequency, over the blade passing frequency, could lead to destructive high cycle fatigue problems.
Current unsteady computational fluid dynamics codes have the ability to predict vortex shedding, however little experimental data is available particularly in modern designed compressor blades which have relatively blunt trailing edges. Since the Turbopropulsion Laboratory of the Naval Postgraduate School current has a set of second-generation Controlled-Diffusion blades installed in the Low Speed Cascade Wind Tunnel, it is ideally suited to perform a vortex shedding study on these blades.

SUMMARY: Three inlet flow angles (31, 33 and 35 degrees) were investigated at three Reynolds numbers (280,000, 380,000 and 640,000). Laser-Doppler-velocimetry (LDV) and hotwire surveys were performed across the wake to determine the unsteady flow parameters associated with the vortex shedding. Spectral analyses of the hotwire measurements were performed to determine the vortex shedding frequency and extend of the vortices.

THESES DIRECTED:

Brown, P., "Investigation of Vortex Shedding in a Cascade of Controlled-Diffusion Compressor Blades," Masters Thesis, Naval Postgraduate School, March 2002.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Turbine, Laser, Velocimetry, Vortex Shedding

TURBINE TIP-LEAKAGE FLOWS

G. V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center - Aircraft Division

OBJECTIVE: This project entails non-intrusive, laser-Doppler-velocimetry (LDV) measurements in the endwall region of a turbine. A paper was presented at the Aerospace Sciences Conference in Reno, NV in January 2001. The specific turbine test article is the turbine of the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME) and the particular hardware was designed and manufactured by Pratt & Whitney for NASA.

SUMMARY: The turbine rig was recommissioned after the heat exchanger between the compressed air supply and the turbine was replaced. A paper was presented on the measurements and computations performed on the first stage of the turbine. During the recommissioning (performed by students in an Advanced Aerodynamics Measurements course) the data acquisition (DAQ) system was upgraded to the latest version of LabView. A HP VEE DAQ system was also developed as part of the upgrade.

PUBLICATIONS:

Hobson, G.V., Anderson, S.C., McKee, J. and Southward, J., "Experimental and Numerical Investigation of the Tip Leakage Flow in the Single Stage Turbine of the Space Shuttle Turbopump," AIAA 2001-0831, presentation at the 39th Aerospace Sciences Conference, Reno, NV, January 2001.

THESES DIRECTED:

Anderson, C.S., "Analysis of the Tip Leakage Flow Field in an Axial Turbine," Masters Thesis, Naval Postgraduate School, June 1999.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Turbine, Laser, Velocimetry, Tip-leakage Flows

CONTINUED DEVELOPMENT OF THE AFFORDABLE GUIDED AIRDROP SYSTEM

Richard M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Yuma Proving Ground

OBJECTIVE: The objective of this proposal is to continue efforts in the development of a low-cost guidance, navigation, and control system for airdrop leading to the demonstration of autonomous guidance of a flat-circular parachute; to support this effort with simulation, hardware development, model development, instrumentation development, and assistance with data analysis, test planning, and system demonstration.

SUMMARY: This part of the project had two components: 1) the development of an aerodynamic model of a controlled flat-circular parachute, and 2) the development of an instrumentation package for personnel parachute application. The previous development of round parachute aerodynamic models was reviewed, and a five-degree-of-freedom model was proposed. An instrumentation package consisting of a datalogger, three low cost rate sensors, three linear accelerometers, a pressure sensor and a GPS card was designed based on similar work at NASA Dryden Flight Research Center.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Airdrop, Parachute, Autonomous Guidance, Modeling

PERSONNEL PARACHUTE INSTRUMENTATION SYSTEM

Richard M. Howard, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Yuma Proving Ground and Naval Postgraduate School

OBJECTIVE: To develop, test, and demonstrate an onboard sensor and data collection package for personnel parachute systems, to determine and record descent rate, oscillation angles, impact velocity, and shock-opening loads. The work is part of a continuing project.

SUMMARY: Based upon former work of NASA Dryden personnel, a prototype instrumentation package using low-cost sensors capable of measuring and recording three angular rates, three linear accelerations, barometric pressure, and GPS position and velocity data was constructed at NPS and tested at Yuma Proving Ground. Tests were performed on "door bundle" and mannequin test articles dropped under parachutes. The instrumentation package was well-suited to the application (being designed to fit on a jumper's chest) with accessible flush switches. Commercial development will follow by a vendor chosen by the sponsor. The project continues, to aid in its commercial development and to complete the inclusion of additional memory storage at various logging rates. Other rate sensors may be tried as well.

OTHER: A prototype instrumentation package was designed, constructed, tested, and delivered.

DoD KEY TECHNOLOGY AREAS: Electronics, Sensors, Modeling and Simulation, Manufacturing Science and Technology

KEYWORDS: Instrumentation, Parachute, Sensors, Testing

INTEGRATION AND FLIGHT TEST OF UCLA'S NAVIGATION COMPUTER ON NAVAL POSTGRADUATE SCHOOL'S UAV *FROG*

Issac I. Kaminer, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: The objective of this proposal is to integrate and flight test the navigation computer developed by UCLA and NASA Goddard on NPS's UAV *FROG*. Specifically, formation flights that include NPS's *FROG* and UCLA's UAV *MULE* will be conducted at Camp Roberts Flight Test Range starting at the end of May 2000 and continuing through September 2001.

SUMMARY: The work was completed in December of 2001. Additional flight testing is planned for 2002.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Air Vehicles, Unmanned Air Vehicles, Flight Test

AEROTHERMOELASTIC STUDIES OF HYPERSONIC FINS

Ramesh Kolar, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center

OBJECTIVE: Aerothermoelastic analysis of a hypersonic fin will be performed. Thermal effects on the structural dynamic response and flutter of the fin will be performed using the aeroelastic analysis tools and for selected temperature distribution. Piston theory and ZONA50 supersonic theory will be used in fin and effects of aspect ratio and in-plane loads will be reported.

SUMMARY: An aerothermoelastic analysis of missile fins at high speeds is performed. Following conclusions may be drawn from the results reported: (1) the thermo elastic analysis shows certain thermal instabilities at elevated temperatures; (2) both the vibrational response and the flutter response analyses are presented within the stable thermal loads. The natural frequencies, in general, decrease as the temperature is increased. The flutter analysis reveals that the fin is flutter free for the speeds considered; (3) The panel flutter analysis show that the panel geometries considered are flutter free if high strength - high stiffness material (Haynes S-230, E = 25E6 psi) is used instead of 2024 Aluminum with E = 10.3E6 psi. Any other geometric variations need analysis prior to construction; (4) Flutter boundaries are obtained for the missile fin under no thermal loading. These flutter boundaries are presented in the form of non-dimensional flutter parameter as a function of Mach number. The flutter boundaries are developed for various altitudes and given as a composite flutter boundary plot. Such flutter boundary design data provides useful information for assessing the flutter margins and structural safety.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Processes, and Structures

KEYWORDS: Missiles, Aeroelasticity, Dynamics, Structures, NASTRAN, Hypersonic Weapons

FINITE ELEMENT MULTI-DISCIPLINARY ANALYSIS OF FLIGHT VEHICLES

Ramesh Kolar, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: Develop new capabilities for a multidisciplinary finite element analysis tool for flight vehicles. Demonstrate by means of validation and verification the capabilities of the simulation software as applied to practical problems.

SUMMARY: NPS developed efficient solution methods and validation utilizing the finite-element method for simulating the dynamic maneuvering of advanced flight vehicles. A multi-disciplinary approach was taken to involve interactions including those between aircraft structures, computational fluid dynamics, controls and design optimization. Several application problems involving large number of degrees of freedom were verified using the software for efficiency and accuracy.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Materials, Processes, and Structures

KEYWORDS: Finite Element Analysis, Multi-Disciplinary Analysis, Computational Fluid Dynamics, Aeroelastic Analysis, Composites and Buckling

IMPROVED TARGET ACCURACY AND SENSOR AIMING FOR RAH-66 WEAPONS SYSTEM

Ramesh Kolar, Research Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Yuma Proving Ground

OBJECTIVE: The objective of this proposal is to use the MSC/NASTRAN Structural Dynamic Model of the RAH-66 helicopter to determine biases between sensor loss and weapon pointing to the target for specified conditions as a function of the flight envelope. Weapons of interest are three–barrel, nose mounted 20-mm turreted Gatling gun. Sensors include FCR, TV, and FLIR. Actual measured gun loads will be used for the analysis.

SUMMARY: Modeling of the structural dynamic behavior of the RAH-66 Comanche vehicle under the specified gun loads was completed. This phase of the work constituted a follow up of the error budgets generated for the weapon systems for the helicopter.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Air Vehicles

KEYWORDS: Helicopter, Rotorcraft, Dynamics/Structures, NASTRAN

MODELING, SIMULATION AND VALIDATION OF RAH-66 WEAPONS SYSTEM

Ramesh Kolar, Research Assistant Professor
E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Yuma Proving Ground

OBJECTIVE: To implement dynamic finite element model of the RAH-66 Comanche helicopter and perform simulations to study the behavior of the weapons system interaction with the helicopter structure.

SUMMARY: The latest dynamic finite element model of the RAH-66 Comanche helicopter developed by Sikorsky was implemented on a NPS computer. Simulation of the structural dynamic behavior using MSC/NASTRAN and PATRAN was performed. Results were correlated with sponsor's data. Response of the helicopter to steady applied loads was performed. Consultation was provided to the sponsor in the modeling and simulation of the gun control system. Also, studies to understand modal testing and dynamic alignment algorithms for the gun control system were performed.

DoD KEY TECHNOLOGY AREAS: Materials, Processes, and Structures, Air Vehicles

KEYWORDS: Modeling and Simulation, Helicopters, Dynamics/Structures, NASTRAN, Dynamic Alignment

MULTI-ROLE ENDURANCE/STRIKE SUPPORT UNINHIBITED COMBAT AIR VEHICLES (UCAVs)

Conrad Newberry, Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: The primary objective of this proposal is to define the system integration issues for two notational UCAVs capable of performing multi-role endurance and/or strike Naval support for the littoral battlespace.

SUMMARY: Two conceptual uninhabited combat air vehicles (UCAVs) were designed to meet multi-role endurance/strike requirements: *FLIPPER* and *SEA ARROW*. The *FLIPPER* concept has a thrust-to-weight ratio of 0.77 and a wing loading of 20 psf. It is a multi-role aircraft capable of providing reconnaissance, surveillance, targeting, and data/voice relay (RSTR) to Navy and Marine Corps forces operating in the 21st century. *FLIPPER* has a payload weight of 750 lbf and a takeoff weight of 5,600 lbf. The unit flyaway cost is $5.9M and MMH/FH = 5.3.

SEA ARROW was a semi-tailless aircraft designed for an armed reconnaissance mission. The *SEA ARROW* concept has a thrust-to-weight ratio of roughly 0.65 and a wing loading of approximately 32. *SEA ARROW* carries a weapons payload of 1,500 lbf and can takeoff in 387 feet (40 kt head wind); 785 feet with no wind. Takeoff weight is 15,000 lbf. Unit flyaway cost is $9.5M; MMH/FH = 8.8 and mission effectiveness is 0.609 (compared to unity).

DoD KEY TECHNOLOGY AREAS: Human Systems Interface

KEYWORDS: Uninhabited Combat Air Vehicles, Medium Altitude Endurance, Naval Support, Multi-Role

ASRAAM MISSILE LAUNCH LOAD ANALYSIS

Max F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center

OBJECTIVE: To contribute to the analysis of missile launch loads from F-18 aircraft

SUMMARY: Consulting services were provided to the Naval Air Warfare Center, Patuxent River, to assist in the analysis of the ASRAAM missile high G launch loads performed by the Nielsen Engineering & Research Company

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Missile Aerodynamics, Missile Launch Loads

COMPUTATIONAL STUDY OF ABRUPT WING STALL

Max F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Office of Naval Research

OBJECTIVE: The objective of the proposed investigation is the computational prediction of abrupt transonic wing stall using advanced Navier-Stokes codes.

SUMMARY: Reynolds-averaged Navier-Stokes computations were completed to predict the transonic flow over a complete f/A-18 E/F aircraft configuration and over a simplified fighter aircraft wing/LEX/body configuration. Data in the pre and post-stall regime were obtained and it was shown that a small change in the cross-sectional area distribution in the aft body has a significant effect on the onset of wing stall, thus indicating that transonic area ruling has the potential to alleviate transonic wing stall.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Transonic Aerodynamics, Wing Stall, Computational Fluid Dynamic

DEVELOPMENT OF MICRO-AIR VEHICLES

Max F. Platzer, Distinguished Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Research Laboratory

OBJECTIVE: To develop a micro-air vehicle which uses flapping-wing propulsion.

SUMMARY: A number of computational and experimental investigations of the flow over flapping wings suitable for the propulsion of micro-air vehicles were completed. The computational studies were based on two-dimensional potential flow and viscous Navier-Stokes solutions for the flow over flapping airfoils and airfoil combinations. Several wind tunnel models of varying scales and complexity were developed and tested in a low-speed flow visualization tunnel. The thrust was measured directly and compared with the numerical predictions. Measured thrust for the larger model compared well with the numerical predictions. Also, the oscillatory flow was measured with a laser-doppler velocimeter. The smaller model revealed a significant Reynolds number effect which could be explained as being due to the onset of dynamic stall vortices shed from the leading edges.

THESES DIRECTED:

Castro, B.M., "Multi-Block Parallel Navier-Stokes Simulation of Unsteady Wind Tunnel and Ground Interference Effects," Ph.D. Dissertation, September 2001.

Mahmoud, O.M.K.M., "Experimental Investigation of Low Speed Flow over Flapping Airfoils and Airfoil Combinations," Ph.D. Dissertation, September 2001.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Micro-Air Vehicles, Low-Speed Aerodynamics, Unsteady Aerodynamics, Flapping Wings

EVALUATION OF A NEW APPROACH TO EFFICIENT TRAJECTORY OPTIMIZATION

I. Michael Ross, Associate Professor
Department of Aeronautics and Aeronautics
Fariba Fahroo, Associate Professor
Department of Applied Mathematics
Sponsor: Draper Laboratory

OBJECTIVE: The objective of this research was to evaluate the applicability of spectral methods to handle nonlinear trajectory optimization problems. Included in this evaluation is the question of the efficiency of spectral methods to handle state discontinuities such as those arising in launch vehicle trajectory optimization.

SUMMARY: The evaluation was conducted in part at Draper Labs (Ross) and at NPS (Fahroo). Services were also provided to Draper Labs in the form of advising staff (Draper) and MIT graduate students. Several trips by Professor Fahroo to Draper labs further facilitated cooperative research between Draper Labs and NPS. Significant outcomes of this cooperative research were: an independent demonstration by Richard Philips (Draper) in the use of pseudospectral methods for launch vehicle trajectory optimization, and an MIT Masters' Thesis by Jeremy Rea (advised by Ross and others) which showed the feasibility of using pseudospectral methods for model-predictive guidance in addition to its capability to handle table look-up data.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Optimal Control, Trajectory Optimization, Launch Vehicle Guidance

EVALUATION OF A PREDICTIVE METHOD FOR NEAR-OPTIMAL GUIDANCE

I. Michael Ross, Associate Professor
Department of Aeronautics and Aeronautics
Fariba Fahroo, Associate Professor
Department of Applied Mathematics
Sponsor: Draper Laboratory

OBJECTIVE: The goal of this research was to evaluate the capability of solving linear-time-varying quadratic optimal control problems without the aid of differential Riccati equations.

SUMMARY: Linear time-varying systems with quadratic cost arise quite frequently in the design of guidance and control systems. In particular, they facilitate the notion of neighboring optimal control laws. For predictive control methods to work efficiently, it is necessary to avoid solving Riccati equations on-line. In this project a new method developed at NPS was evaluated for on-line (i.e. real-time) implementation. This method does not use Riccati methods but solves the accessory minimum problem using an indirect Legendre pseudospectral method. The evaluation process demonstrated that the new method was capable of solving such problems on line without incurring loss in accuracy employed in the approximation.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles

KEYWORDS: Guidance and Control, Symplectic Boundary Value Problems, Riccati Methods.

SABBATICAL RESEARCH AT DRAPER LABS

I. Michael Ross, Associate Professor
Department of Aeronautics and Aeronautics
Sponsor: Naval Surface Warfare Center

OBJECTIVE: This proposal is for researching the design of optimal gimbal tumbling for INS error reduction during the boost and bus phases of the Trident Missile. The task will be performed as part of the Principal Investigator's sabbatical at the Charles Stark Draper Laboratory in Cambridge, MA.

SUMMARY: Classified.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Inertial Navigation, Missile Guidance

ADVANCED FAN AND COMPRESSOR DEVELOPMENT STUDIES

Ray P. Shreeve, Professor
Garth V. Hobson, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center - Aircraft Division

OBJECTIVE: To develop or validate tools for the design of advanced compression systems for Navy engines. Four tasks are ongoing: (i) to obtain experimental measurements and observations of CD blade stall for CFD code validation; (ii) to develop a geometry package geared to the design (by CFD analysis) of swept transonic blading, and to facilitate design optimization; (iii) to install and test an advanced transonic axial stage, and thereby establish the means to evaluate more advanced designs economically; (iv) to develop advanced measurement capability.

SUMMARY: (i) Three-component LDV measurements of the end-wall flow field of the cascade were performed in a thesis study by Caruso. Measurements were taken on four grids spanning one blade passage from center span to the end wall, one upstream of the cascade and three downstream in the wake. Hence a full 3D data set, including loss measurements obtained in the earlier thesis study by Carlson, was produced at an inlet flow angle of 40 degrees (+4 deg. Incidence). Also, a paper on the measurement of separation bubbles at three different Reynolds numbers in the cascade was published in the *AIAA Journal of Propulsion and Power*. (ii) A new Bezier-surface representation of axial transonic blading, requiring only 32 control points and two parameters, was developed in an earlier Ph.D. study by Abdelhamid. The ability to easily introduce sweep etc. was demonstrated. A current Ph.D. study aims to use the geometry package to optimize a fan rotor design. To date it has been shown that the Sanger rotor can be modified to increase pressure ratio, flow rate and efficiency, with lower blade stresses. The procedure will now be applied to other rotors. (iii) Test data from the compressor rig are being compared with code analysis. The complexity of the computational model of the Sanger stage has been increased by including an inlet grid which models the spinner and inlet ducting, and tip grids over both the rotor and stator. Preliminary calculations of the 100% and 80% near peak efficiency points have produced improved results. (iv) Application of pressure-sensitive paint to the Sanger rotor test is awaiting the construction of an aluminum and Plexiglas modular case wall. A tip-timing technique for measuring the vibrations of rotor blades using laser-light probes, was implemented successfully in the HCF/Spin Test Research program.

PUBLICATIONS:

Hobson, G.V., Hansen, D.J., Schnorenberg, D.G. and Grove, D.V., "Effect of Reynolds Number on Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," *Journal of Propulsion and Power*, Vol. 40, No. 1, pp 154-162, January-February 2001.

THESES DIRECTED:

Caruso, T.M., "Three-Component LDV Measurements of Corner Vortices over Second-Generation Controlled-Diffusion Compressor Blades in Cascade," Masters Thesis, Naval Postgraduate School, September 2001.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Controlled-Diffusion Blading, LDV Measurements, Compressor Cascade Stall, Transonic Compressor Design, Pressure-Sensitive Paint (PSP)

HCF/SPIN TEST RESEARCH

Ray P. Shreeve, Professor
Garth V. Hobson, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center - Aircraft Division and Naval Postgraduate School

OBJECTIVE: To develop high-cycle fatigue (HCF) spin-test techniques using an engine-scale vacuum spin-pit. Following the successful implementation of air-jet excitation (AJE), oil-jet excitation (OJE) and eddy-current excitation (ECE) techniques using two small rotors, present goals are to apply similar techniques to full-scale engine rotors, and to perform tests to evaluate blade damping techniques. The program is conducted in close association with NAWCAD, and with the participation of Hood Technology Corporation, jointly funded by the Air Force.

SUMMARY: An exploratory test program using a small titanium rotor and a program to evaluate stick dampers in a full-scale XTE 66 LPT-2 partially bladed rotor were completed. Peak-peak unsteady stress levels of 11kpsi were produced with ECE in the eleven-inch diameter titanium rotor, but tests were limited to a few minutes by heating. OJE produced over 80kpsi, but an oil recovery system needed to be developed to enable endurance testing using oil. AJE at 8, 10, 12 engine order (EO, or RPM) was used to excite the lowest resonant mode of the XTE 66 rotor, and information on damping was obtained. Attempts to excite higher order modes at 200EO with a partial array of air jets gave very low unsteady stress levels, but the reasons were well understood. Progressively higher levels of excitation were obtained with ECE when magnets were used at the blade tips as well as the trailing edges, and when silver plating was applied to the nickel blade surfaces. However in the targeted mode, excitation levels were not high enough to evaluate the effectiveness of dampers. Considerable progress was made in unsteady measurement techniques. A two laser-light probe 'time-of-arrival' blade deflection system was calibrated successfully (to strain gauge measurements) to infer unsteady stresses in all blades. It was seen then that the blade response depended on its position in the rotor, and that very consistent behavior was obtained if a start-stop test procedure and averaging was used.

The refurbished spin-pit facility at the turbopropulsion laboratory serves as the Navy research facility for high-cycle fatigue (HCF) – related spin testing. Eddy-Current excitation of an F119 fan is planned first, in association with hood technologies, Inc. Unsteady response measurement and analysis capability will be developed, and will be applied in a follow-on program, which will be a coordinated part of the national HCF initiative. The overall program will be conducted in close collaboration with NAWCAD personnel and will support the NAWCAD program in HCF.

PRESENTATIONS:

Mercadal, M., von Flotow, A. and Roesler, C., "Results of Eddy Current Excitation of Blade Vibration in a Series of Rotors," 6th National Turbine Engine High Cycle Fatigue Conference, Jacksonville, FL, 5-8 March 2001.

Shreeve, R.P., Hobson, G.V., Seivwright, D.L. and Pickering, R., "Navy HCF/Spin Test Program," 2001 Passive Damping Action Team Meeting, Pittsburg, PA, 31 July 2001.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Spin Testing, High Cycle Fatigue, HCF, Spin-Pit Facility, Gas-Turbine Blade Excitation

SATELLITE SERVICING LABORATORY

Michael G. Spencer, Assistant Professor
Department of Aeronautics and Astronautics
Sponsor: Air Force Research Laboratory and Naval Postgraduate School

OBJECTIVE: The objective of this research is to develop an autonomous servicing spacecraft simulator and test-bed. The simulator will be used for the development and validation of autonomous, neural network based control algorithms as well as various hardware elements necessary for autonomous rendezvous and docking, space manipulator control, and satellite servicing operations.

SUMMARY: The first year of effort was very successful with considerable progress made in the design and development of the servicing satellite test-bed. The servicing satellite simulator was designed as a test-bed for the autonomous rendezvous/docking systems. The simulator includes a robotic servicing vehicle and a separate target vehicle.

The servicing vehicle has a modular design so as to accommodate and test various vision and docking systems. A robotic arm will be able to integrate different end-effectors for "soft dock" and grapple tests with the target vehicle. The realtime control system will be developed and implemented using a PC based system with Lab VIEW to enable rapid integration and testing. Cold gas thrusters and a momentum wheel are to be used to translate and rotate the servicing vehicle about the workspace. A summary of the work accomplished and the current design of the vehicle follows:

- Power and computer connections were installed in the laboratory room.
- Tables, cabinets and computers have been installed to support two students design and research efforts.
- Most of the components necessary to build the servicing satellite vehicle have been procured. These items include a reaction wheel, air thrusters, air pads, air tanks, cameras, arm motors, a rate sensor, accelerometers, a PXI control computer, and a Data Acquisition computer.
- Software to support the lab that has been purchased included Lab VIEW, Matlab and a student version of AutoCad.

In addition to the support from NPS, additional reimbursable support ($50K) was obtained from the Air Force Research Laboratory. These funds directly supported the procurement of critical hardware for the satellite test-bed. Future reimbursable funding from AFRL is expected for fiscal year 02. Two Naval graduate students have signed on with the lab to do their thesis research in the development and testing of the satellite test-bed. The students are currently involved in the lab by designing and preparing the lab for the assembly and testing of the robotic servicing vehicle.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Satellite Servicing, Autonomous Control, Neural Networks, Free-Flying Satellites

RESEARCH IN DAMPER FREE ROTOR DESIGN BASED ON MAPLE NONLINEAR SIMULATION

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: U.S. Army Research Office

OBJECTIVE: The objective of this work was to derive the full non-linear lead-lag equations of motion for a multiblade rotor. Apply this new expanded analysis in two areas with high potential for eliminating reliance on mechanical damping in helicopters. These are by introduction of structural tailoring to provide nonlinear hingeless rotor lead/lag characteristics, and by swashplate feedback for increased lead/lag stability. Initial work was to treat the dynamic system in a vacuum. This was to be followed by introducing

unsteady aerodynamics into the problem. The significance of this new research is that it has the potential to benefit all military services, since Army, Navy, Marines and the Air Force employ helicopters extensively. Lead-lag instability, when it occurs, can build up to destructive proportions in a matter of seconds.

SUMMARY: Work for the year 2001 was carried out by P.I., Prof. E. Roberts Wood of NPS, with support from Professor David Canright of the NPS Mathematics Dept., CDR Mark A. Couch, NPS Lecturer and doctoral student, Assistant Professor Robert L. King of Mississippi State University, and Dr. Ronald W. Duval, Advanced Rotorcraft Technology, Inc. of Mountain View, CA. Work was in three areas:

- Toward improved methodology for the ARO-NPS Rotor-Fuselage Nonlinear Dynamic Model and reducing computation time.
- Toward development of a full-scale OH-6A helicopter for ground and flight tests of concepts to control or eliminate ground and air resonance.
- Toward incorporating unsteady aerodynamic theory into the ARO-NPS Rotor-Fuselage Nonlinear Dynamic Model with applications to Higher Harmonic Control, tiltrotor aeromechanics, and the vortex ring state flight regime (See NPS presentation for ARO Ninth Aeroelastic Workshop at University of Michigan which has a work-in-progress report on this work).

The year 2001 marked the completion of this 3-year ARO project (ARO Project 37803-EG). To summarize, the project resulted in 10 conference presentations and publications and one refereed journal publication. For NPS it resulted in one Ph.D. thesis (King, R. L.), one Engineer's degree thesis (Robinson, C. S.), two M. S. degree theses (Rafanello, S. P. and Weissenfels, R. D.), and one Ph.D. degree in work (Couch, M. A.).

PUBLICATIONS:

King, R.L., "Nonlinear Inplane Flexbeam Stiffness Provides Rotor System Stability Without Lag Dampers," *Journal of the American Helicopter Society*, Vol. 46, No. 4, pp. 283-289, October 2001.

PRESENTATIONS:

Couch, M.A. and Wood, E.R., "Exploring Methods to Incorporate Unsteady Aerodynamics into Nonlinear Rotor Dynamics Simulation," Ninth International Workshop on Aeroelasticity of Rotorcraft Systems, University of Michigan, Ann Arbor, MI, 22-24 October 2001.

THESIS DIRECTED:

Ehlers, G.E., "Hi-Fidelity Simulation and Prediction of Helicopter Single Point External Load Stabilization," Masters Thesis, Naval Postgraduate School, September 2001.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Rotorcraft, Helicopter, Ground/Air Resonance, Damperless, VTOL/Maple/Simulink

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMANCHE HELICOPTER

E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsor: Comanche Program Office

OBJECTIVE: The objective of this proposal in the present task calls for structural optimization of the Comanche tailcone against 23-MM HEI threat. There are two phases to this work. One phase consists of correlation of our DYSTRAN simulation with results of live fire tests conducted at Aberdeen Proving Ground on the tailcone fabrication under the STA (Static Test Article) phase of the program. The second phase consists of exploring the integrity of the EMD design of the RAH-66 to the 23 MM HEI threat. In effect, the STA phase serves as verification of DYTRAN modeling compared to real world firing tests. The EMD phase is being conducted to improve the design strength of the tailcone.

SUMMARY: Work on the DYTRAN project was completed in the spring of '01. At that point the Army asked NPS to change the focus of this research to aeroacoustics. Specifically NPS was asked to take an existing Army program for aural detection of helicopters that had been coded in Fortran and to rewrite this program in a modern, computer friendly language, and also include in the new version updates from other aural detection programs to bring it up to state-of-the-art. Much of this work is now complete. Professor Wood assisted by Associate Professor Steve Baker of the NPS Physics department and MAJ Ron Selvy (USMC) are in the process of completing the work. They have taken the previous code (ICHIN) which stands for "I can hear it now" and developed a new code in Matlab. The new code is named MICHIN, where the added M signifies Matlab. Army plans call for sound jury tests to be done in the fall to verify MICHIN.

DoD KEY TECHNOLOGY AREAS: Computing and Software

KEYWORDS: Helicopter, Rotorcraft, Dynamics, Structures, NASTRAN/DTRAN

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

2001
Faculty Publications and Presentations

PUBLICATIONS/PRESENTATIONS

JOURNAL ARTICLES

Carr, L.W., Chandrasekhara, M.S., Wilder, M.C. and Noonan, K.W., "Effect of Compressibility on Suppression of Dynamic Stall Using a Slotted Airfoil," (AIAA Paper 98-0332), *Journal of Aircraft*, Vol. 38, No. 2, pp. 296-309, March-April 2001.

Chandrasekhara, M.S., Wilder, M.C. and Carr, L.W., "Compressible Dynamic Stall Control Using Dynamic Shape Adaptation," (AIAA Paper 99-0655), *AIAA Journal*, Vol. 39, No. 10, pp. 2021-2024, October 2001.

Chandrasekhara, M.S., Wilder, M.C. and Carr, L.W., "Compressible Dynamic Stall Control: Comparison of Two Approaches," (Invited AIAA Paper 99-3122), *Journal of Aircraft*, Vol. 38, No. 3, pp. 448-453, May-June 2001.

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudospectral Method," *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 2, pp. 270-277, March-April 2001.

Fahroo, F. and Ross, I.M., "A Second Look at Approximations to Differential Inclusions," *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 1, January-February 2001.

Hobson, G.V., Hansen, D.J., Schnorenberg, D.G. and Grove, D.V., "Effect of Reynolds Number on Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," *Journal of Propulsion and Power,* Vol. 40, No. 1, pp. 154-162, January-February 2001.

Hobson, G.V., Hansen, D.J., Shnorenberg, D.G. and Grove, D.V., "Effect of Reynolds Number on Separation Bubbles on Controlled-Diffusion Compressor Blades in Cascade," *AIAA Journal of Propulsion and Power*, Vol. 17, No. 1, 2001.

Jones, K.D., Lund, T.C. and Platzer, M.F., "Experimental and Computational Investigation of Flapping Wing Propulsion for Micro Air Vehicles," *AIAA Progress in Aeronautics and Astronautics*, pp. 307-339, 2001.

Kaminer, I.I., Pascoal, A.M., Kang, W. and Yakimenko, O., "Integrated Vision/Inertial Navigation Systems Design Using Nonlinear Filtering," *IEEE Transactions on Aerospace and Electronics,* Vol. 37, No. 1, pp. 158-172, January 2001

Kaminer I., Pascoal A., Kang W. and Yakimenko O.A., "Application of Nonlinear Filtering to Navigation System Design Using Passive Sensors," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 1, pp. 158-172, 2001.

King, R.L., "Nonlinear Inplane Flexbeam Stiffness Provides Rotor System Stability Without Lag Dampers," *Journal of the American Helicopter Society*, Vol. 46, No. 4, pp. 283-289, October 2001.

Lai, J.C.S. and Platzer, M.F., "Characteristics of a Planning Airfoil at Zero Freestream Velocity," *AIAA Journal*, Vol. 39, No. 3, pp. 531-534, 2001.

Ross, I.M., Park, S.Y. and Porter, S.E., "Gravitational Effects of Earth in Optimizing Delta-V for Deflecting Earth-Crossing Asteroids," *Journal of Spacecraft and Rockets,* Vol. 38, No. 5, 2001.

Song, G. and Agrawal, B., "Vibration Suppression of Flexible Spacecraft During Attitude Control," *Acta Astronautics,* Vol. 49, No. 2, pp. 73-83, 2001.

von Backstrom, T.W., Hobson, T.V., Crossman, B. and Shreeve, R.P., "Numerical Analysis of a CFD Design Compressor Stage," *AIAA Journal of Propulsion and Power,* 2001.

Weber, S. and Platzer, M.F., "Computational Simulation of Dynamic Stall on the NLR 7301 Airfoil," *Journal of Fluid and Structures,* Vol. 14, pp. 779-798, 2000.

PUBLICATIONS/PRESENTATIONS

CONFERENCE PAPERS

Agrawal, B. and Okano, S., "Microelectromechanical Systems for Space Applications," *Proceedings of the 11th International Workshop on Physics of Semiconductor Devices*, New Delhi, India, 11-15 December 2001.

Agrawal, B. and Senenko, C., "Attitude Dynamics and Control of Bifocal Relay Mirror Spacecraft," AAS 01-418, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Brophy, C.M., Sinibaldi, J.O. and Sexton, N., "Fuel/Air Initiator Development for Pulse Detonation Engines," *Proceedings of the 18th International Colloquium on the Dynamic of Explosions and Reactive Systems*, Seattle, WA, 29 July–3 August 2001.

Brophy, C.M., Sinibaldi, J.O. and Netzer, D.W., "Effects on Fuel Distribution on Pulse Detonation Engine Operation and Performance," 15th International Symposium on Air Breathing Engines, Bangalore, India, September 2001.

Castro, B.M., Jones, K.D., Ekaterinaris, J.A. and Platzer, M.F., "Analysis of the Effect of Porous Wall Interference on Transonic Airfoil Flutter," AIAA-2001-2725, 31st AIAA Fluid Dynamics Conference and Exhibit, Anaheim, CA, 11-14 June 2001.

Chen, H., Agrawal, B., Longman, R., Phan, M. and Edwards, S., "Rejection of Multiple Unrelated Periodic Disturbances Using MELMS with Disturbance Identification," AAS/AIAA Space Flight Mechanics Meeting, Santa Barbara, CA, 11-15 February 2001.

Chen, H., Agrawal, B. and Longman, R., "Approaches to Matched Basis Function Repetitive Control," AAS-01-369, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Couch, M. and Wood, E.R., "Exploring Methods to Incorporate Unsteady Aerodynamics into Nonlinear Rotor Dynamics Simulations," 9th International Workshop on Aeroelasticity of Rotorcraft Systems, Ann Arbor, MI, October 2001.

Duren, R., Couch, M. and Wood, E.R., "An Analysis of 'Vortex Ring State' Encounters from Flight Test Data with Application to an Onboard Warning System" Investigation into Tiltrotor Aeromechanics Phenomena, NASA Ames Research Center, Mountain View, CA, June 2001.

Duren, R., Couch, M. and Wood, E.R., "An Analysis of 'Vortex Ring State' Encounters from Flight Test Data with Application to an Onboard Warning System," *Proceedings of the 57th American Helicopter Society (AHS) Annual Forum*, Washington, DC, 9-11 May 2001.

Duren, R., "F/A-18 C/D Avionics Architecture Upgrade Study," F/A-18 Advanced Weapons Laboratory Combined Country Conference (AWL C^3): Building Synergies – A Look to the Future, NAWCWD, China Lake, CA, 6-7 March 2001.

Hespanha J., Yakimenko O., Kaminer I. and Pascoal A., "Linear Parametrically Varying Systems with Brief Instabilities: An Application to Integrated Vision/IMU Navigation," *Proceedings of the 40th IEEE Conference on Decision and Control*, Orlando, FL, 12-15 December 2001.

Hespanha, J., Yakimenko, O., Kaminer, I. and Pascoal, A., "Stability and Performance Analysis of LPV Systems with Brief Instabilities," *Proceedings of the 9th Mediterranean Conference on Control and Automation*, Dubrovnik, Croatia, 27-29 June 2001.

Hespanha, J., Yakimenko, O., Kaminer, I. and Pascoal, A., "LPV Systems with Brief Instabilities: Application to Integrated Vision/IMU Navigation," *Proceedings of IEEE European Control Conference*, Porto, Portugal, 4-7 September 2001.

PUBLICATIONS/PRESENTATIONS

Hespanha, J., Yakimenko, O., Kaminer, I. and Pascoal, A., "Analysis of LPV Systems with Brief Instabilities with Application to Integrated Vision/IMU Navigation," *Proceedings of IFAC Workshop on Adaptation and Learning in Control and Signal Processing*, Como, Italy, 29-31 August 2001.

Hobson, G.V., Anderson, S.C., McKee, J. and Southward, J., "Experimental and Numerical Investigation of the Tip Leakage Flow in the Single Stage Turbine of the Space Shuttle Turbopump," AIAA 2001-0831, 39th Aerospace Sciences Conference, Reno, NV, January 2001.

Jones, K.D., Duggan, S.J. and Platzer, M.F., "Flapping Wing Propulsion for a Micro-Air Vehicle," AIAA Paper No. 2001-0126, 39th Aerospace Sciences Meeting, Reno, NV, 8-11 January 2001.

Jones, K.D. and Platzer, M.F., "On the Use of Vortex Flows for the Propulsion of Micro-Air and Sea Vehicles," NATO/RTO Applied Vehicle Technology Panel Meeting, Loen, Norway, 7-11 May 2001.

Johnson, J., Yakimenko O., Kaminer I. and Dellicker S., "On the Development and Pre-Flight Testing of the Affordable Guided Airdrop System for G-12 Cargo Parachute," *Proceedings of 16th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar*, Boston, MA, 21-24 May 2001.

Proulx, R. and Ross, I.M., "Time-Optimal Reorientation of Asymmetric Rigid Bodies," AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Ross, I.M., Yan, H. and Fahroo, I.M., "A Curiously Outlandish Problem in Orbital Mechanics," AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Ross, I.M. and Fahroo, F., "A Pseudospectral Transformation of the Convectors of Optimal Control Systems," *Proceedings of the First IFAC Symposium on System Structure and Control*, Prague, Czech Republic, 29-31 August 2001.

Ross, I.M. and Fahroo, F., "Convergence of Pseudospectral Discretizations of Optimal Control Problems," *Proceedings of the Conference on Decision and Control*, Orlando, FL, December 2001.

Searles, D.S., Brophy, C.M., Sinibaldi, J.O., Venner, M.J. and Johnson, C.W., "Soot Production Characteristics for JP-8+100, and JP-10," 27th JANNAF EPTS, Brooks Air Force Base, San Antonio, TX, November 2001.

Shreeve, R.P., Hobson, G.V., Seivwright, D.L. and Pickering, R., "Navy HCF/Spin Test Program," HCF Passive Damping Action Team Meeting, Carnegie Mellon University, Pittsburg, PA, 31 July 2001.

Shreeve, R.P., "HCF/Spin Test Research Review," Navy/Air Force Joint Program Review, Monterey, CA, 29 November 2001.

Sinibaldi, J., Brophy, C.M., Li, C. and Kailasanath, K., "Investigation of Detonation Wave Diffraction During the Ignition of Pused Detonation Engines," 2nd Joint Meeting of the Combustion Institute, 25-18 March 2001.

Sinibaldi, J.O., Brophy, C.M., Li, C. and Kailasanath, K., "Initiator Detonation Diffraction Studies in Pulse Detonation Engines," 37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, July 2001.

Song, G., Vlattas, J., Johnson, S. and Agrawal, B., "Active Vibration Control of a Space Truss Using a Lead Zicronate Titanate Stack Actuator," *Proceedings Institute of Mechanical Engineers*, Vol. 215, Part G, 2001.

Spencer, M.G., "Development of a Servicing Satellite Simulator," *Proceedings of the AIAA Space 2001 Conference*, Albuquerque, NM, August 2001.

Tuncer, I. and Platzer, M.F., "Computational Investigation of Flow Through a Louvered Inlet Configuration," AIAA-2001-2477, 19th AIAA Applied Aerodynamics Conference, Anaheim, CA, 11-14 June 2001.

Yan, H., Fahroo, F. and Ross, I.M., "Optimal Feedback Control Laws by Pseudospectral Approximations," *Proceedings of the American Control Conference*, Paper No. AC01-AIAA1015, Arlington, VA, 25-27 June 2001.

Yakimenko, O., Kaminer, I., Lentz, W. and Ghyzel, P., "On Shipboard Navigation for Unmanned Air Vehicles Using Infrared Vision," *Proceedings of AIAA Guidance, Navigation, and Control Conference*, Montreal, Canada, 6-9 August 2001.

Yakimenko, O., Kaminer, I. and Dellicker, S., "Preliminary Design and Control Strategy Analysis of the Affordable Guided Airdrop System," *Proceedings of the 9th Mediterranean Conference on Control and Automation*, Dubrovnik, Croatia, 27-29 June 2001.

CONFERENCE PRESENTATIONS

Agrawal, B. and Okano, S., "Microelectromechanical Systems for Space Applications," 11th International Workshop on Physics of Semiconductor Devices, New Delhi, India, 11-15 December 2001.

Agrawal, B. and Senenko, C., "Attitude Dynamics and Control of Bifocal Relay Mirror Spacecraft," AAS 01-418, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Chen, H., Agrawal, B. and Longman, R., "Approaches to Matched Basis Function Repetitive Control," AAS-01-369, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Canada, 30 July–2 August 2001.

Chen, H, Agrawal, B., Longman, R., Phan, M. and Edwards, S., "Rejection of Multiple Unrelated Periodic Disturbances Using MELMS with Disturbance Identification," AAS/AIAA Space Flight Mechanics Meeting, Santa Barbara, CA, 11-15 February 2001.

Couch, M.A. and Wood, E.R., "Exploring Methods to Incorporate Unsteady Aerodynamics into Nonlinear Rotor Dynamics Simulation," Ninth International Workshop on Aeroelasticity of Rotorcraft Systems, University of Michigan, Ann Arbor, MI, 22-24 October 2001.

Shreeve, R.P., Hobson, G.V., Seivwright, D.L. and Pickering, R., "Navy HCF/Spin Test Program," 2001 Passive Damping Action Team Meeting, Pittsburg, PA, 31 July 2001.

TECHNICAL REPORTS

Chandarsekhara, M.S., "Fluid Mechanics of Compressible Dynamic Stall Control Using Dynamically Deforming Airfoils," Final Report submitted to Army Research Office, November 2001.

Chandarsekhara, M.S., "An Exploratory Investigation of Pulsatile Blowing to Control Compressible Dynamic Stall over an Oscillating NACA 00125 Airfoil," STIR Final Report submitted to Army Research Office, April 2001.

Duren, R., "F/A-18 C/D Avionics Architecture Upgrade Study," F/A-18 Advanced Weapons Laboratory Mission Systems Review, 21 February 2001.

Duren, R., "F/A-18 C/D Avionics Architecture Upgrade Study Status Report," 26 January 2001.

Duren, R., "F/A-18 C/D Avionics Architecture Upgrade Study: An Introduction to CPU Tech," 12 January 2001.

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

Thesis Abstracts

CONCEPTUAL DESIGN TOOLS FOR THE NPS SPACECRAFT DESIGN CENTER

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Master of Science in Astronautical Engineering-September 2001
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The thesis surveys and develops spacecraft design techniques and tools involving the integration of collaborative/concurrent engineering (CE) for spacecraft design, specifically in the areas of spreadsheet and CAD/CAE software, for the NPS Spacecraft Design Center (SDC). The applicability of solid modeling to the spacecraft design process is also explored. A previous class design is modeled using a solid modeling tool and the results compared against the time and effort required for the original. In addition, two CE software tools obtained from commercial and university sources are installed in the SDC, improved, documented if necessary, and evaluated. The capabilities are evaluated with regard to learning curve, CE and their utility to the curriculum. A User's Guide for one of the software tools is written, as no documentation existed for it prior to this thesis. In addition, procedures for spacecraft design utilizing the SDC are developed in order to enhance student design capabilities and further their educational experience.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Spacecraft Design Techniques, Collaborative/Concurrent Engineering

PERFORMANCE AND SPACE BORNE APPLICATION ANALYSIS OF THE HIGHER ORDER CYCLOSTATIONARY BASED CLASSIFIER

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Testing of the Higher Order Cyclostationary Based Classifier (HBC) is conducted to evaluate system operational performance. Utilizing Higher Order Cyclostationary (HOCS) analysis techniques, the HBC is designed to automatically detect and classify communication and radar signals contained in input signal samples. While test results utilizing earlier data were inconclusive on the effectiveness of the system, a more rigorous testing for Binary Phase-Shift Keying (BPSK) modulation scheme is herein carried out. The results of the HBC analysis reveal a system which experiences difficulty in performing modulation detection and classification of the input data at signal-to-noise ratios above 10 dB. The HBC automatic band-of-interest detector also shows evidence of interfering with accurate signal classification results. Recommended improvements to the algorithms and interface are presented to address these and other observed trends. An application of the HBC system to the Naval Research Laboratory's Pre-Configured Interface Payload (PCIP) program are assessed for space borne testing of the HBC system.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Computing and Software, Sensors, Modeling and Simulation

KEYWORDS: Cyclostationary, Cyclostationarity, Digital Signals, Signal Classification, Signals Intelligence (SIGINT), Spacecraft Payload Integration, Pre-Configured Interface Payload (PCIP)

ADAPTIVE MULTI-LAYER LMS CONTROLLER DESIGN AND ITS APPLICATION TO ACTIVE VIBRATION SUPPRESSION ON A SPACE TRUSS

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This thesis develops an adaptive controller that actively suppresses a single frequency disturbance source at a remote position and tests the system on the NPS Space Truss. The experimental results are then compared to those predicted by an ANSYS finite element model. The NPS space truss is a 3.7-meter long truss that simulates a space-borne appendage with sensitive equipment mounted at its extremities. One of two installed piezoelectric actuators and an Adaptive Multi-Layer LMS control law were used to effectively eliminate an axial component of the vibrations induced by a linear proof mass actuator mounted at one end of the truss. Experimental and analytical results both demonstrate reductions to the level of system noise. Vibration reductions in excess of 50dB were obtained through experimentation and over 100dB using ANSYS, demonstrating the ability to model this system with a finite element model. This thesis also proposes a method to use distributed quartz accelerometers to evaluate the location, direction, and energy of impacts on the NPS space truss using the dSPACE data acquisition and processing system to capture the structural response and compare it to known reference signals.

DoD KEY TECHNOLOGY AREA: Space Vehicles, Modeling and Simulation

KEYWORDS: Active Vibration Suppression, Piezoceramic Actuators, Impact Analysis, Adaptive Controller, LMS

THREE-COMPONENT LDV MEASUREMENTS OF CORNER VORTICES OVER SECOND-GENERATION, CONTROLLED-DIFFUSION, COMPRESSOR BLADES IN CASCADE

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A detailed investigation of the three-dimensional flow in a cascade of second-generation controlled-diffusion compressor stator blades, at off-design inlet-flow angle, is reported. Three-component fiber-optic Laser-Doppler Velocimetry (LDV) surveys were made to fully map the flow at one plane upstream of the cascade and at three planes downstream. The measurements were performed at an inlet flow Mach number of 0.22 and a Reynolds number, based on chord length, of 640,000. The inlet surveys documented the approaching flow field in detail to establish the inlet boundary conditions for numerical simulations. At the downstream planes, total velocity distributions, total turbulence kinetic energy distributions, secondary flow velocity vector and contour plots are presented. The downstream surveys confirmed the existence of secondary flow vortices produced by the end wall. Surface vector and contour plots of non-dimensional velocity and total turbulence kinetic energy detail the complex flow field, including the size and location of the corner vortex system.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: LDV Measurements, Compressor Ccascade Stall, Transonic Compressor Design, Controlled Diffusion Blading

MULTI-BLOCK PARALLEL NAVIER-STOKES SIMULATION OF UNSTEADY WIND TUNNEL AND GROUND INTERFERENCE EFFECTS

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Dissertation Supervisor: Max F. Platzer, Department of Aeronautics and Astronautics

A numerical investigation of unsteady wind tunnel and ground interference effects is carried out in the time domain to study the transonic flutter characteristics of the NLR 7301 section inside a wind tunnel and the thrust generation characteristics of a NACA0014 airfoil plunging near a ground plane. A parallelized, multi-block, deforming grid, unsteady flow-solver is coupled with a two-degree-of-freedom structural model.

For the transonic flutter problem, two types of porous-wall boundary-conditions are implemented and tested for the boundaries representing the tunnel walls. The type of porous boundary condition is found to influence significantly both steady and unsteady solutions. Results show that the free-flight flutter behavior may differ significantly from the behavior found in a porous wind tunnel because of the strong dependence on the tunnel porosity parameter and the proximity of the walls.

An analysis of the trailing edge boundary condition is performed for the airfoil in ground effect. The computations show that this boundary condition influences the solution only when non-linearities are present in the flow-field, although parameters averaged through a cycle of oscillation are not affected significantly. The same behavior is observed for the influence of the turbulence model on the fully-turbulent, unsteady computations. However, the best agreement with low Reynolds number, experimental data is obtained when the flow is assumed laminar and no turbulence model is applied.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Low Speed Aerodynamics, Transonic Flutter, Computational Fluid Dynamics

HI-FIDELITY SIMULATION AND PREDICTION OF HELICOPTER SINGLE POINT EXTERNAL LOAD STABILIZATION

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The helicopter has been used since its early development for external transport of large or bulky loads to small austere locations. Among the problems encountered as lift capability and airspeeds increased was that of divergent load oscillations due to load aerodynamics The most problematic are the single point external loads displaying unsteady aerodynamics and coupled yaw-pendulum modes accounting for the instability of cargo containers. However, a lack of simulation models for unsteady aerodynamics renders simulation and analysis incapable of predicting the critical speeds at which such loads become unstable. This thesis attempts to provide a stabilization system for controlling the yaw degree of freedom for the single point external load. Empirical models of the yaw resistance at the hook and of the yaw moments due to vortex shedding were developed and tuned using flight test data and lab measurements. Several load stabilization systems were considered, and a horizontal and vertical tail fin assembly was selected This thesis presents simulation model improvements required for a simulation to match flight results for the load yaw, along with the design, modeling and optimization of the fin stabilization system, and a simulation assessment of the envelope expansion obtained from both passive and active stabilization.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Modeling and Simulation

KEYWORDS: Rotocraft, Helicopter, Aerodynamics

DESIGN AND EVALUATION OF A DIGITAL FLIGHT CONTROL SYSTEM FOR THE FROG UNMANNED AERIAL VEHICLE

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The importance of unmanned aerial vehicles (UAVs) to current and future military operations cannot be understated. This rapidly developing field requires the ability to quickly develop and evaluate advanced control concepts. The FROG UAV serves as a test bed for advanced control and sensor projects at the Naval Postgraduate School. Previous control system projects have made use of a low performance electromechanical autopilot onboard the UAV. This autopilot imposed significant limitations on the responsiveness of the FROG. This project developed and tested an off board digital flight control system for use in lieu of the previous electromechanical device.

The digital flight controller was developed using the MatrixX rapid prototyping system and a previously validated dynamic model of the FROG. Surrogate flight control servo actuators were characterized in the laboratory and added to the plant model. Classic inner/outer loop controllers were developed for yaw damping and speed, altitude and heading control. The system was then successfully demonstrated with hardware in the loop in the lab.

The FROG was then instrumented and a command uplink latency of 170 ms was discovered. This introduced excessive phase lag into the system, which drove the flight controllers unstable. An alternate serial uplink method was developed and tested which reduced the command latency to 76 ms however the remaining phase lag resulted in limit cycle oscillation. Laboratory tests indicated that the current flight controller could withstand a maximum of 50 ms command path delay; without modification.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Unmanned Aerial Vehicles, Flight Control System, Flight Controller

TESTING AND DEVELOPMENT OF A SHROUDED GAS URBINE ENGINE IN A FREEJET FACILITY

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Karlheinz E.Woehler, Professor Emeritus

Testing and analysis of a shrouded turbojet engine with possible application for high speed propulsion on low cost Unmanned Combat Aerial Vehicles (UCAV), Unmanned Aerial Vehicles (UAV) and missiles was the subject of this thesis. The possibility of a turbojet providing thrust at subsonic conditions and the ramjet section providing the thrust in the supersonic regime exists. The combined cycle engine (CCE) could be incorporated into a variety of applications.

The building of a new freejet facility and engine test rig at the Naval Postgraduate School enabled dynamic testing of the ongoing development of a turboramjet. The freejet facility and new engine stand performed without exception. The shrouded engine was dynamically tested in a freejet up to Mach 0.4. The engine performance measurements closely matched those predicted by a cycle analysis program, GASTURB.

Computational fluid dynamics (CFD) was used to analyze the supersonic inlet at a design point of Mach 2. The results provided by the CFD code, OVERFLOW, matched theoretical flow parameters. The intake design was slightly modified to enhance performance of shock waves in the supersonic flight regime.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: Micro-Turbojet, GASTURB, Engine Shroud, Turboramjet, Sophia J450, Microturbine

SUPERSONIC FLOW FIELD VISUALIZATION STUDIES OF THE M∞=6 PRICE WAVERIDER PLANFORM

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Supersonic tests of the conical flow derived M∞=6 (design) Price waverider planform were conducted using the Naval Postgraduate School wind tunnel. These tests are part of a continuing effort to study the characteristics of waverider configured vehicles. Two sting-mounted, flat-plate stainless-steel Price waverider planform models were utilized for testing in the NPS 4-inch by 4-inch cross section supersonic blowdown wind tunnel. Tests at Mach numbers of M∞=1.7, 2.8 and 4 were attempted but flowfield studies were only completed at M∞=4. Sting mount flow blockage (choked flow) prevented test section starting at freestream test Mach numbers of M∞=1.7 and 2.8. Horizontal (side-view) and vertical (top-view) mounted shadowgraph pictures and pressure sensitive paint images were taken at pitch angles of a=0°, 2° and 4°. The Mach 4 shadowgraph and pressure sensitive paint results correlate well with previous CFD results using the three-dimensional Price waverider model. The choked flow tests at M∞=1.7 and 2.8 are discussed in detail; suggestions are given for future work in this Mach number test spectrum.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Supersonic Tests, Waverider Configured Vehicles, Price Waverider Planform

INVESTIGATION OF CROSS FLOW FAN PROPULSION FOR LIGHTWEIGHT VTOL AIRCRAFT

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As world population increases, road and airport congestion will become increasingly prevalent. A small, cheap VTOL aircraft which can be flown from a driveway to the workplace parking lot would reduce traffic congestion and travel time. A lightweight, single seat commuter type VTOL aircraft is envisioned as the solution to this problem. To achieve a goal of minimum weight, the aircraft aerodynamic design should be optimized for forward flight. Vertical thrust augmentation from a propulsion unit contained within the fuselage would have little detriment to forward flight aerodynamics, and the cross flow fan can be accomodated as such. Cross flow fan propulsion has not been seriously considered for aircraft use since an LTV Vought Systems Division study for the U.S. Navy in 1975. Despite an indepth knowledge of the design parameters and airflow relationships in cross flow fans, the existing data supports the hypothesis that with further development the thrust efficiency and thrust-to-weight ratio could improve to the point where this thrust producing method is viable. This study investigates the incorporation of rotary engine powered cross flow fan propulsion in a hypothetical lightweight VTOL aircraft and concludes that cross flow fan propulsion is viable but only with further investigation of power plant technology and fan design parameters and relationships.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Air Vehicles

KEYWORDS: VTOL, Cross Flow Fan, Ducted Propeller

A NUMERICAL STUDY OF FUEL-OPTIMAL LOW-EARTH-ORBIT MAINTENANCE

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This thesis studies the fuel optimal periodic reboost profile required to maintain a spacecraft experiencing drag in low-earth-orbit (LEO). Recent advances in computational optimal control theory are employed, along with a Legendre-Gauss-Lobatto Pseudospectral collocation code developed at the Naval Postgraduate School, to solve the problem. Solutions obtained by this method are compared against a previous study. Key issues were checking the optimality of the solutions by way of the necessary conditions and the behavior of the solution to changes in the thruster size. The results confirmed Jensen's findings of propellant savings of one to five percent when compared against a middle altitude Forced Keplerian Trajectory (FKT). Larger savings are predicted if compared against a finite-burn Hohmann transfer with drag. The costates estimates compared favorable against necessary conditions of Pontryagin's Minimum Principle. Analysis of the switching function yielded periods of thrust-modulated arcs. The optimal thrust profile appears to be a thrust-modulated burn to raise the orbit followed by an orbital decay and a terminating thrust-modulated arc. For a sufficiently low thrust-control authority, the switching structure includes a maximum thrust arc. Indirect optimization techniques to confirm these findings were unsuccessful.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Orbital Mechanics, Optimization, Optimal Control Theory, Orbit Maintenance

TELEMETRY SYSTEMS ANALYSIS AND DESIGN

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Second Reader: Norm Sorensen, National Reconnaissance Office Chair Professor

The Navy has a valuable opportunity to improve its own products and operations efficiency by showing its future leaders and designers how to design effective and viable telemetry, tracking, and commanding (TT&C) systems, and their operation. One system is the FLTSAT military communications constellation of spacecraft, one of which has been a static display at the Naval Postgraduate School (NPS) until June, 2000. The primary objective was to make this spacecraft operational and thus provide a new operational spacecraft laboratory for other NPS students. This thesis may also be used as a primer for the space engineering or space operations student regarding TT&C systems design. Great effort has been taken to document and discuss current design practices and standards adopted by DoD laboratories, test facilities, and operation centers. A TT&C system designed for a spacecraft incorporating all the traditional subsystems (payload, thermal, structural, power, TT&C, attitude control) is included.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Other (Communications)

KEYWORDS: Space Vehicles, Communications

UNMANNED AERIAL VEHICLES AND SPECIAL OPERATIONS: FUTURE DIRECTIONS

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Advances in computing, miniaturization, imaging, and data transmission technologies are precursors to a more important role for UAVs in warfare. UAVs are likely, first, to revolutionize the way reconnaissance and surveillance are conducted, second, to increase the capabilities of small units, third, to join manned platforms in the conduct of assault and attack missions, and finally help provide the numerous nodes necessary to facilitate both the digital connectivity and swarming forces envisioned in future network-centric formations.

This thesis focuses on answering six questions:

-What missions can UAVs perform?
-What missions should UAVs perform?
-What type of UAV is appropriate for each mission?
-How can SOF use UAVs?
-Who should own the UAV (from a SOF perspective)?
-What level of control is required and where?

Results include what UAV missions and types could support special operations, which of these should be performed by UAVs organic to special operations, and which should be performed by the Services' UAVs, as well as recommendations for future command and control of UAVs supporting special operations. Results are presented in matrix form for easy correlation of related factors. The thesis concludes with a twenty-year prognostication of UAV development and recommends areas for future study.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Battlespace Environments, Command Control and Communications, Electronic Warfare, Sensors

KEYWORDS: Unmanned Aerial Vehicles, UAV, Special Operations Forces, SOF, Future of Warfare

HARDWARE INTEGRATION OF PARACHUTE GUIDANCE, NAVIGATION, AND CONTROL FOR THE AFFORDABLE GUIDED AIRDROP SYSTEM (AGAS)

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This study is a continuation of a previous work concerning the Affordable Guided Airdrop System (AGAS), a parachute structure that integrates low-cost guidance and control into fielded cargo air delivery systems. This thesis sought to integrate the previous studies and algorithms into developmental prototypes for test and evaluation (DT&E). Several objectives and tasks were completed in the course of this research and development. A RealSim(r) executable on an Integrated Systems, Incorporated (ISI) AC-104 real-time controller integrated actual Vertigo(r), pneumatic muscle actuators (PMAs) into the MATRIX-X. The environment simulation model used in the previous work to validate, analyze and improve the simulation model. A ground station utilizing the model's control algorithms, a downlink of platform position and attitude data, and a Futaba(r) Pulse Code Modulated uplink demonstrated controlled guidance of a round cargo parachute (G-12). This system evolved as an RS-232 serial control RF modem uplink replaced the PCM control. After evaluating, validating, and improving the algorithms using the ground station control algorithm was written in C-code for incorporation into an autonomous system. The results from the drops were then analyzed in the MATRIX_X (r) to further improve the model and qualitatively evaluate

improved control strategies. Conclusions and recommendations for further study were drawn from this project.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Affordable Guided Airdrop System, AGAS, Parachute Guidance, Navigation and Control

EXPERIMENTAL INVESTIGATION OF LOW SPEED FLOW OVER FLAPPING AIRFOILS AND AIRFOIL COMBINATIONS

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A wind tunnel investigation of low speed flow over flapping airfoils and airfoil combinations was performed using flow visualization and laser Doppler velocimetry. Specifically, three cases were studied: A NACA0014 airfoil oscillating in a sinusoidal plunge mode, A NACA0014 airfoil oscillating in a sinusoidal plunge mode near a ground plane, and two NACA0014 airfoils arranged in a biplane configuration and oscillating in counterphase in a sinusoidal plunge mode. The plunge amplitude-to-airfoil chord ratio was 0.4, the reduced frequency of oscillation was 1.0 and the Reynolds number based on airfoil chord was set at 8760.

Conditionally sampled measurements of the axial flow velocity were taken at numerous flow held points providing detailed information about the flow features generated by this type of flapping motion. These measurements were complemented by time-averaged flowfield data and by visualization of the instantaneous flow held at various points during the flapping cycle. Furthermore, the thrust generated by the sinusoidal plunge motion was measured with a laser range. The results show that vortex shedding occurs both from the airfoil leading and trailing edge.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Low Speed Flow, Flapping Airfoils, Axial Flow Velocity, Low Speed Aerodynamics

EVALUATION OF THE USE OF GPS-AIDED WEAPONS TO ATTACK MOVING TARGETS

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The current intelligence gathering and strike decision infrastructure is optimized to handle geographically and temporally fixed targets. When tasked to respond to targets that require near immediate engagement, however, the system is stressed to the limit of its capability. When these time sensitive targets are capable of relocating, the process of rapidly applying lethal force becomes even more complicated. This thesis examines the problems associated with attacking a moving target using low cost GPS-aided standoff weapons, without an integrated weapon seeker. It begins with a discussion of the history and evolution of the Navy's ability to attack time sensitive moving targets, and provides the description of a system that could address shortcomings noted. MATLAB(Simulink(was used to develop a model to simulate the proposed system, and determine the responses to various combinations of identified error sources. The results of the research showed that the type of system proposed is technically feasible.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Command, Control, and Communications, Conventional Weapons, Sensors, Modeling and Simulation, Other (Time Critical Strike)

KEYWORDS: GPS, Weapon, Modeling, CEP, Time Sensitive Targets, Command Control and Communications, Conventional Weapons, Sensors, Modeling and Simulation, Time Critical Strike, Stand-off Weapons

MICROELECTROMECHANICAL SYSTEMS FOR SMALL SATELLITE APPLICATIONS

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Microelectromechanical systems (MEMS) have been developing for the past few decades, but recent spaceflight demonstrations have highlighted the potential of this technology as an attractive paradigm shift in how aerospace systems should be developed, maintained and used as the dawn of a new space age emerges. MEMS will generate a revolution in the way people see and control tomorrow's satellites by combining technological advances in sensors, actuators, reactionary systems, spacecraft attitude control systems, information processing and storage with the miniaturization of these components. MEMS will enable the realization of decentralizing satellites and, therefore, create a paradigm shift in the conceptual operation and development process of how people think about using satellites. The vision of what can be achieved from space is no longer bound by what an individual satellite can accomplish, rather, a number of much smaller cooperating satellites can share the functionality at a lower cost in development and production. This thesis will validate the concept of MEMS and its applicability to space and conclude by examining possible paths that the Naval Postgraduate School microsatellite, NPSAT1, can take to reducing subsystem mass and power through the use of MEMS components.

DoD KEY TECHNOLOGY AREA: Sensors, Other (Microelectromechanical Systems)

KEYWORDS: Micromlectromechanical Systems, MEMS, Nanosatellites, Microsatellites, NPSAT1, Gyroscopes

ANGULAR RATE ESTIMATION FOR MULTI-BODY SPACECRAFT ATTITUDE CONTROL

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Second Reader: Harold A. Titus, Department of Electrical and Computer Engineering

Spacecraft with high performance attitude control systems requirements have traditionally relied on imperfect mechanical gyroscopes for primary attitude determination. Gyro bias errors are connected with a Kalman filter algorithm that uses updates from precise attitude sensors like star trackers. Gyroscopes, however, have a tendency to degrade or fail on orbit, becoming a life-limiting factor for many satellites. When errors become erratic, pointing accuracy may be lost during short star gaps. Unpredictable gyros degradations have impacted NASA spacecraft missions such as Skylab and Hubble Space Telescope as several DoD and ESA satellites. An alternative source of angular rate information is a software implemented real tie dynamic model. Inputs to the model from internal sensors and known spacecraft parameters enable the tracking of total systemangular momentum from which body rates can be determined. With this technique, the Kalman filter algorithm provides error corrections to the dynamic

model. The accuracy of internal sensor and input parameters determine the effectivenes of this angular rate estimation technique. This thesis presents the background for understanding and implementation of the technique into a representative attitude determination system. The system is incorporated into an attitude simulation model developed in SIMULINK to evaluate the effects of dynamic modeling errors and sensor inaccuracies. Results are presented that indicate that real time dynamic modeling is an effective method of angular rate determination for maneuvering multi-body spacecraft attitude control systems.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Modeling and Simulation

KEYWORDS: Dynamic Gyro, Kalman Filter, Attitude Determination, Rate Estimation, Star Trackers, Attitude Simulation, Multi-body Dynamics, Quaternion, MATLAB, SIMULINK

PRELIMINARY DESIGN CODE FOR AN AXIAL STAGE COMPRESSOR

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Current two-dimensional preliminary design codes use structured programming, which is rigid and does not allow the user to vary parameters easily. This study uses object-oriented programming to allow the user to vary all selectable parameters in a familiar Windows operating environment. The programmed design is based on the assumptions of axial and free-vortex flow between blade rows, simple radial equilibrium, and a thermally and calorically perfect gas. The program allows a fan or core stage design and uses an open architecture to facilitate upgrades and extensions.

Using the Naval Postgraduate School's (NPS) transonic compressor design as input, the preliminary design code output was compared to the detailed throughflow design of the transonic compressor. The results agreed reasonably well with detailed throughflow design. With some minor improvements this code can easily be used to develop a preliminary design that can be optimized to the user's requirements.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power

KEYWORDS: Axial and Free-Vortex Flow, Transonic Compressor, Axial Stage Compressor

TARGETING AND FIRE CONTROL SYSTEM ANALYSIS OF THE NEW TURKISH ATTACK HELICOPTER "THE AH-1Z KINGCOBRA"

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In May of 1997, the Turkish Military issued a Request for Proposal for the purchase of 145 attack helicopters. Turkey has chosen Bell Helicopter's KingCobra as its attack helicopter. The major difference between the USMC version of AH-1Z and the Turkish version KingCobra is the Targeting and Fire Control System. Bell Helicopter Textron has chosen Lockheed Martin to develop and build a new targeting system, the Target Sight System (TSS). The TSS will contain Lockheed Martin's 3-5μm midwave staring array FLIR. On the other hand, the Turkish Secretariat for Defense Industries (SSM) has chosen Aselsan ASELFLIR-300T that contains an 8-12μm longwave scanning second-generation FLIR.

A comparison of range performance for these two systems has been made using the TAWS Field Performance Model. Since the physical parameters on these specific FLIRs are proprietary, the FLIR92 Simulation Model is used to generate performance parameters. These parameters are expected to represent the general characteristics of the two systems. The resultant data is used in the TAWS Field Performance Model to predict the range performances.

The results have showed that the staring array midwave FLIR has longer ranges in the scenarios given in this thesis. This may not represent the real performance of the systems.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Sensors, Other (Thermal Imaging Systems)

KEYWORDS: Thermal Imaging Systems, Targeting, Fire Control Systems, Forward Looking Infrared, FLIR, TAWS, KingCobra, Attack Helicopter, Infrared

EXPLOITATION OF NATIONAL SENSORS FOR TERRAIN CATEGORIZATION (U)

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Abstract is classified.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Sensors, Other (Intelligence, Indications and Warning (I&W))

KEYWORDS: Sensor Fusion, Multispectral Imaging, Imagery Intelligence, TERCAT

SIMULATION OF GUIDED AEROASSISTED MANEUVERS FOR PLANETARY MISSIONS

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Aeroassisted maneuvers are distinguished from purely propulsive maneuvers in that aerodynamic forces are used to assist in orbital maneuvers of spacecraft. These types of maneuvers can vary from aerocapture to direct entry. The NASA Solar System Exploration Program lays the foundation for the future of interplanetary exploration using various versions of these aeroassisted maneuvers. The computer program ACAPS, designed at the Naval Postgraduate School, was developed for the Jet Propulsion Laboratory (JPL) to conduct high-level mission design for exploration missions to Mars. The primary research objective of this thesis was to upgrade the previous version of ACAPS, to produce a tool that provides new capabilities in support of the Solar System Exploration Program. The secondary research objective of this thesis was to provide direct support to JPL mission planners. The first major upgrade was the incorporation of additional planets which allows for simulation at Venus, Saturn, Neptune, and Titan. The second focus of work was the incorporation of guidance to include ballute guidance and the Apollo derived Mars Precision Lander guidance algorithm. This thesis also documents how these upgrades were used to support future missions to Venus, Neptune, Saturn and Titan; particularly in the possibilities of using ballutes.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Modeling and Simulation

KEYWORDS: Aerocapture Simulation (ACAPS), Aeroassist, National Aeronautics and Space Administration (NASA), Jet Propulsion Laboratory (JPL), Mars Sample Return (MSR) Mission, Mars Micromission, MATLAB, SIMULINK, Ballute, Parachute

DETONABILITY OF HYDROCARBON/AIR MIXTURES USING COMBUSTION ENHANCING GEOMETRIES FOR PULSE DETONATION ENGINES

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This research studied combustion enhancing geometries and shock reflection on generating a hydrocarbon/air detonation wave in a combustion tube. Ethylene was used as a baseline fuel to determine the preferable geometries. Propane was then used in later testing because of its combustion similarities with heavy hydrocarbon fuels such JP5, JP8, and JP10. Three criteria were used to measure the effectiveness of the combustion enhancing geometries: ability to generate a detonation, wave speed, and time for shock formation. The evaluated geometries included flow-restricting orifice plates and a Schelkin spiral. The shock reflection was accomplished by a vertical fence (large orifice) placed in the last fourth of the tube length. The optimum geometry was found to be the orifice plate used in conjunction with the spiral. Detonations occurred when using ethylene in this configuration, but did not develop when using propane. Because propane's overall reaction rate is slower than that of simpler fuels, more large- and small-scale turbulence to further enhance combustion needs to be generated to create a detonation wave in a short distance when using complex hydrocarbons, such as propane.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: Detonation, Pulse Detonation Engine, Deflagration to Detonation Transition, DDT

COMPUTERIZED BALLISTIC MODELING OF THE COMANCHE TAILFAN SHROUD

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The U.S. Army has contracted Boeing-Sikorsky to develop the RAH-66 Comanche, a new, armed reconnaissance helicopter that features stealth technology designed to improve survivability when operating in hostile environments. Ballistic testing is required on the Comanche prior to fielding. Computer based simulations are being employed in order to reduce requirements for expensive live-fire testing. This thesis uses a computer program called Dytran from MacNeal-Schwendler to simulate the effects of an explosive round detonating in the Comanche tailfan shroud. Six test cases involving explosions with varying amounts of explosive energy, or specific internal energy, are evaluated. From these tests, a curve showing the percentage of structural failure versus the specific internal energy is plotted. Assuming that 20% structural failure of the model equates to a catastrophic failure, this analysis shows that the analyzed section of the Comanche tailfan shroud can withstand an explosion with a specific internal energy of 2.58 * 1010 in2/sec2. Any potential threat rounds with specific internal energies greater than 2.58 * 1010 in2/sec2 will pose serious threats to the Comanche.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Processes and Structures, Modeling and Simulation

KEYWORDS: Comanche, Ballistic Modeling, Dytran, Tailfan Shroud

A COMPUTATIONALLY EFFICIENT ALGORITHM FOR DISTURBANCE CANCELLATION TO MEET THE REQUIREMENTS FOR OPTICAL PAYLOADS IN SATELLITES

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Vibration control is a very important issue in satellites. The new high-resolution digital imaging devices are especially sensitive to vibrations. Antennas used in laser communications also require a very quiet environment so that their performance is not degraded. The Stewart platform is capable of isolating an optical payload from the noisy spacecraft bus. Until recently, only passive methods were used in all vibration isolation applications. Recent advances in Digital Signal Processing techniques made the development of vibration control algorithms possible, but these usually require large computational power. This work explores using a computationally efficient vibration-isolation method for optical payloads by using hexapods. The method suppresses the vibration at the assigned frequencies and does not affect unassigned frequencies if the plant is linear.

The mathematical analysis includes convergence analysis and the effect of unassigned frequencies in the output. The computational requirements of the algorithm is evaluated and is compared to the Multiple-Error Least Mean Square. The method is very robust to nonlinearities; its performance is comparable to the Multiple-Error Least Mean Square with a fraction of the computational time and memory requirements. It also requires very little plant knowledge. Theoretical results are verified through simulations using a Single-Input/Single-Output plant and a nonlinear hexapod model. The controller was also experimentally validated in two different hexapods and the performance was found to be similar to or better than the performance obtained with the Multiple-Error Least Mean Square method when a noisy reference signal is used.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Vibration Control, Optical Payloads in Satellites, Disturbance Cancellation

REMOTE NANOSATELLITE FORMATION DESIGNS WITH ORBIT PERTURBATION CORRECTIONS AND ATTITUDE CONTROL/PROPULSION SUBSYSTEM CORRELATION

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The innovative idea of distributing the functionality of current larger satellites among smaller, cooperative satellites has been sincerely considered for assorted space missions to accomplish goals that are not possible or very difficult to do with a single satellite. Additionally, the utilization of smaller satellites is maximized within formations and clusters to conduct missions such as interferometry and earth-sensing. This paper presents a methodology to describe, populate and analyze numerous formation designs employing the use of Hill's equations of motion to describe a formation's dynamics. These equations of motion are then programmed into a MATLAB code to produce Cartesian elements for input into a Satellite Tool Kit((STK) simulation that demonstrates numerous possible cluster formation designs. These simulations are then used to determine ?V requirements for overcoming LEO-type perturbations that were modeled within STK's High Precision Orbit Propagator (HPOP).

Finally, components from two subsystems [Attitude Determination and Control (ADCS) and Propulsion], using the ?V calculations from the simulation analysis and current advances in MicroElectroMechanical systems (MEMs) and nanosatellite technology, are presented based on a mass constraint of 10kg for the entire satellite.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion, Space Vehicles, Modeling and Simulation

KEYWORDS: Satellite Formation, Orbit Dynamics, STK, Nanosatellite, and Satellite Propulsion

ANALYSIS OF TRACKING AND IDENTIFICATION CHARACTERISTICS OF DIVERSE SYSTEMS AND DATA SOURCES FOR SENSOR FUSION

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In the Command and Control mission, new technologies such as 'sensor fusion' are designed to help reduce operator workload and increase situational awareness. This thesis explored the tracking characteristics of diverse sensors and sources of data and their contributions to a fused tactical picture. The fundamental building blocks of any sensor fusion algorithm are the tracking algorithms associated with each of the sensors on the sensor platform. In support of this study, the MATLAB program 'fusim' was written to provide acquisition managers a tool for evaluating tracking and sensor fusion algorithms.

The fusim program gives the user flexibility in selecting: sensor platforms, up to four sensors associated with that platform, the target types, the problem orientation, and the tracking algorithms to be used with the sensors. The fusim program was used to compare tracking algorithms in a multiple sensor/multiple target environment. Specifically, the Probabilistic Data Association Filter, the Interacting Multiple Models Filter, the Kalman Filter and the Constant Gain Kalman Filter were evaluated against multiple maneuvering, non-maneuvering, and fixed targets. It is recommended that this study be continued to evaluate advanced tracking and data association techniques, to expand the program to allow attribute tracking and identification, and to study the Human-Machine Interface aspects of sensor fusion..

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Sensors, Command Control and Communications, Computing and Software

KEYWORDS: Data Fusion, Sensor Fusion, Tracking, Tracking Algorithms, Kalman Filter, Probabilistic Data Association, PDA, Interacting Multiple Models, IMM, Simulation

ANALYSIS OF A MAGNETIC THREE-AXIS STABILIZED ATTITUDE CONTROL SYSTEM FOR THE NPSAT1 SPACECRAFT

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The NPSAT1 satellite uses an active magnetic torque rod system, with a magnetometer for attitude determination, to maintain 3-axis stabilization, with a slightly gravity gradient friendly structure.

This thesis will examine the performance of three combinations of programs and simulation models for the NPSAT1 satellite attitude control system. The models include a magnetic control law with a reduced order estimator to generate torque commands to achieve spacecraft nadir pointing and a magnetic rate (Bdot) control law to reduce spacecraft angular rates. The performances of two Bdot mode switching designs are compared. Also, a case is made for the benefits of priming the system's reduced estimator prior to mode switching.

All of the control methods analyzed appear to be valid control methods to achieve three-axis attitude stabilization using only magnetic torquers for active control. The most efficient control method analyzed incorporates a hand-off method from a magnetic rate (Bdot) control loop to a magnetic control loop. The results of this analysis indicates that the best use of this method is to perform the Bdot hand-off following the achievement of a predetermined combined angular rate.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: NPSAT1, Attitude Control System

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